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Contents

In This Issue

The analysis can be extended to any degree of refinement, but the more complicated the question the more cumbersome the analysis. In order to know anything it is necessary to know everything, but in order to talk about anything it is necessary to neglect a great deal. Joan Robinson (1941)

Economists are often caught in an awkward dilemma: accused of simplifying problems away or complicating them beyond comprehension. The demands of analyzing real world problems often require that we lean toward complexity if our results are to be taken seriously. But, complexity will often lead to the familiar accusation that we are living in an ivory tower. Some middle ground must be sought.

The three articles in this issue illustrate that a compromise between simplicity and complexity sometimes yields insights and solutions to problems that would otherwise remain hidden. This should be the goal of most applied economic research.

The lead article by Tom Hertel builds a persuasive case for using general equilibrium instead of partial equilibrium models for analyzing agricultural trade issues. The past decade has seen a great deal of activity in the quantitative analysis of agricultural trade with the high profile of agriculture in the Uruguay Round of GATT negotiations focusing international attention on the consequences of domestic farm policies for world trade. Given this stage, Hertel studies two questions. First, what happens to global food sales if farm and food policies as well as nonfood trade interventions are liberalized but the European Community's Common Agricultural Policy is kept in place and, second, what happens if the EC's food policies are also reformed? Hertel's conclusion is that agricultural and nonagricultural interests in trade cannot be separated. Consequently, the avenue to global, agricultural reform requires the involvement of all interest groups, whether they represent food or nonfood sectors.

The research by Moore, Gollehon, and Negri helps establish a foundation for evaluating irrigation water conservation and input substitution by estimating irrigated crop production functions using farm-level observations. Their analysis covers 13 irrigated crops with data from 17 Western States. For each crop, results include output elasticities of irrigated water, returns to scale, and the marginal rate of technical substitution between land and water. Their results have one immediate policy implication: since output elasticities for irrigation water are very inelastic for each crop examined, farmers should be able to mitigate many of the production impacts of water conservation efforts.

Nick Powers illustrates how to measure the exercise of market power by growers who can influence quantities sold to selected markets via a Federal marketing order. He uses the Federal marketing order for California-Arizona navel oranges that authorized handler prorates, enabling the industry to establish a weekly maximum amount for shipment as a case study. Powers finds that growers exercised some market power (but not complete monopolistic power) via marketing order prorates prior to 1983 but have exercised less power since 1983 when a policy curtailing growers' use of prorates was established.

Gary Williams finds much to recommend the book, *Commodity Advertising and Promotion,* edited by Kinnucan, Thompson, and Chang. Williams thinks this collection of papers from a recent conference plays a valuable role by organizing into a single volume the most recent research on a wide range of issues related to generic promotion. He argues that the book would be a valuable addition to the library of anyone involved in promotion activities, ranging from those evaluating advertising effectiveness to policymakers and producer groups.

John Horowitz gives the book, *Environmental Policy and the Economy,* edited by Dietz, van der Ploeg, and van der Straaten, a slightly downbeat assessment. He believes this collection of conference papers is a mixed bag, most papers being weak, but some containing noteworthy analysis. It is only as a comprehensive picture of a broad topic that this book comes close to succeeding and, perhaps, justifying its purchase or a reader's time.

David Letson enthusiastically endorses Thore's *Economic Logistics: The Optimization of Spatial and Sectoral Resource, Production, and Distribution Systems.* Letson believes that Thore's economics is an aggregation of models of individual producers, shippers, and warehouses all coming together to form a logistical system solving for optimal market prices and quantities. The book provides a synthesis of mathematical programming with a creative demonstration of its capabilities. Thus, it is well-suited for the graduate classroom, and for everyone else "it is a reminder of tools

developed over the past half-century and their power when in creative hands."

Phil Kaufman concludes that *Economics of Food Safety,* edited by Julie Caswell, fills a void in the literature but is not without a few blemishes. He finds the collection of papers to be an excellent sampling of current research issues and applications that will help both economists and policymakers to understand food safety concerns. He indicates that the volume is an ambitious beginning and will motivate other researchers to fill in the gaps. Kaufman also feels that chapters stressing research methods rather than the empirical aspects of food safety analysis may have limited appeal to lay readers and policymakers.

Mark Simone describes *The Political Economy of Agricultural Trade and Policy: Toward a New Order for Europe and North America,* edited by Michelmann, Stabler, and Storey, as accessible, generally devoid of equations, but lacking much new information to serious students of the Uruguay Round of GATT negotiations. The collection may be most useful to those wishing to understand the agricultural policy process in a number of different countries. Given the 1990 collapse of GATT negotiations, which postdates publication of this volume, Simone would be interested in having these same authors discuss regional trade issues.

Multiple Job-holding among Farm Families, edited by Hallberg, Findeis, and Lass, is reviewed by Leslie Whitener. She thinks the book, an updated overview, is a must-read for analysts embarking on research studies. However, it falls short in identifying gaps in the current literature and in suggesting future research and policy directions. Whitener suggests that the book, while not complete, is a good start.

James Blaylock
David Smallwood

Partial vs. General Equilibrium Analysis of Trade Policy Reform

Thomas W. Hertel

Abstract. *A standard, multiregion general equilibrium (GE) model is developed and contrasted with typical partial equilibrium (PE) models of agricultural trade for two trade policy reform experiments. In the case of reforms affecting both food and nonfood sectors, the PE model has difficulty predicting changes in patterns of food production and trade. When the shock is sector-specific, however, PE models perform very well. In this case, the major benefit of GE analysis is its ability to draw the link between agricultural and nonagricultural interests in trade policy.*

Keywords. *General equilibrium, trade policy.*

Over the past decade, there has been a tremendous demand for quantitative analysis of agricultural trade. The Uruguay Round of the GATT negotiations has focused international attention on the consequences of domestic farm policies for world trade in farm and food products. Demand for agricultural analysis has largely been met with partial equilibrium models of agricultural trade (Tyers and Anderson, 1986; Roningen and Dixit, 1989; OECD, 1987).[1] However, multiregion general equilibrium models, with varying degrees of agricultural detail, have also entered the debate (Burniaux and others, 1988; Burniaux and van der Mensbrugghe, 1990; Harrison and others, 1989; Horridge and Pearce, 1988; McDonald, 1989; McDougall and others, 1991; Nguyen and others, 1991). In this paper, I will develop a fairly standard multiregion, general equilibrium model of agricultural trade, illustrating how it differs from a "typical" partial equilibrium model in its predictions of the consequences of trade policy reform.

The 1992 stalemate in the GATT negotiations over an acceptable package of agricultural reforms motivated the two policy experiments in this article. The controversial reform of the European Community's Common Agricultural Policy (CAP) occasions the first experiment, which liberalizes all *non-CAP* farm and food policies as well as nonfood trade interventions. A comparison of partial and general equilibrium predictions of the subsequent change in the global pattern of food sales shows sizable discrepancies between the two. This serves to highlight the difficulty of using a partial equilibrium model to analyze the consequences of a multisectoral shock.

The starting point for the second experiment is the new equilibrium following reform of non-CAP policies. At this point, the only trade distortions remaining in the model are those due to EC food policies. The second policy experiment, which involves reform of the CAP, is a sector-specific shock, so partial equilibrium analysis provides a good approximation to the general equilibrium changes in the global food system. Indeed, since it is a single-region shock, a one-region partial equilibrium model provides a fairly accurate assessment of changes in the EC food sector. However, by including other regions and sectors in the analysis, one can derive important policy information essential for illustrating the benefits of international reform of farm and food policies.

Structure of the Global Data Base

The global data base used in this study is built upon data developed by the Australian Industry Commission in support of the SALTER model of world trade (Jomini and others, 1991; Dee and others, 1992).[2] The basic structure of this data base is displayed in figure 1. At the top is a variable representing the Value of Output for tradeable commodity i, located in region r, evaluated at Agents' (producers') prices: VOA(i,r). (For a data set with 3 industries and 9 regions, there would be 27 components in this matrix.) The SALTER data base tracks the distribution of output in each industry/region across all other

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[1]One of the more comprehensive collections of work in this area may be found in the volume edited by Goldin and Knudsen. Sources are listed in the References section at the end of this article.

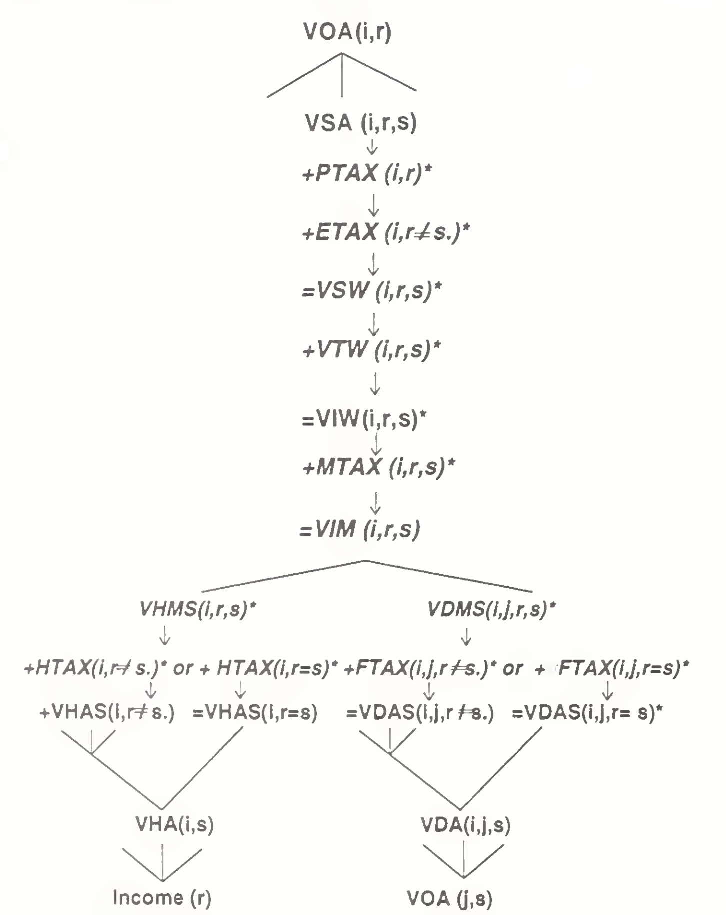
[2]Specifically, the SALTER-I data base was used. Due to limitations of this early release, a number of modifications were required to ensure proper closure of the model. These are discussed in Hertel, Gehlhar, and McDougall (1992). The associated data base program is implemented using GEMPACK (Codsi and Pearson, 1988). This program is available from the author upon request, Dept. of Ag. Econ., Purdue University, West Lafayette, IN 47907. Telephone: (317) 494-4199.

regions. VSA(i,r,s) (fig. 1) represents the Value of Sales of commodity i from region r to region s at Agents' prices. These bilateral trade flows are crucial for analyses of regional trading arrangements or product differentiation and imperfect competition. Bilateral flows also introduce market share as a key determinant of interregional gains from policy reform in foreign markets.

To move from producer prices to world market prices, VSA(i,r,s) must be adjusted for any producer taxes/subsidies [PTAX(i,r)] and export taxes [ETAX(i,r,s)]. The SALTER data base permits export taxes to vary by destination. For example, a country may engage in targeted export subsidies, or the export tax rate may vary due to *compositional* differences in exports of products within category i, which are themselves taxed at equal but varying rates. Finally, export taxes/subsidies do not apply to domestic sales, so that ETAX(i,r,r) = 0.

The addition of production and export taxes yields the Value of Sales i from r to s, evaluated at World prices. For exports ($r \neq s$), these sales are equal to observed trade flows on an f.o.b. basis. By adding bilateral transport and insurance costs, VTW(i,r,s), one arrives at the Value of *Imports* at World prices, VIW(i,r,s). Once bilateral tariff rates are accounted for, one obtains the value of imports at domestic market prices. (Duty rates vary across sources for the same three reasons export taxes vary by route.)

Figure 1
Key concepts in the global data*



*Basic data are provided in italics. All other variables are inferred from these data.

A special feature of the SALTER data base is that it tracks imports to particular uses.[3] This gives rise to the Value of Household purchases at Market prices by Source: VHMS(i,r,s). Similarly, the Value of Derived demands at Market prices by Source is denoted: VDMS(i,j,r,s). Household and firm taxes on traded goods also vary by source. Once these are accounted for, one obtains purchases at agents' prices by source: VHAS(i,s,r) and VDAS(i,j,r,s). When summed over sources, they yield total purchases of i: VHA(i,r) and VDA(i,j,r).

In addition to the information in figure 1, the SALTER data base includes purchases of endowment commodities (land, labor, and capital) by sector, as well as regional savings and investment levels. Furthermore, SALTER distinguishes between private and public household demands. However, in this article, I aggregate all final demand into a single composite. While the resulting model is inappropriate for the analysis of alternative fiscal policies, the emphasis here is on the interregional incidence of trade policy reforms. Aggregating public and private demands obtains an unambiguous measure of regional welfare. Also, the resulting model is considerably simplified. For many other purposes, disaggregation of regional households is essential, and this can be accomplished in a manner similar to that shown below for firms.

Model Structure

It is "accounting" (as opposed to behavioral) equations in an applied general equilibrium (AGE) model that make it general equilibrium in nature.[4] For this reason, these equations provide the logical starting point in this exposition, and their conditions formally characterize the difference between partial and general equilibrium analyses.

Accounting Relationships

The data base overview (fig. 1) reflects many of the accounting relationships embodied in the global

[3]*Sourcing* of imports is assumed to be the same for all purchasers of a given commodity.

[4]The term "accounting" refers to equations that must hold if the social accounting matrix underpinning the model is to balance. For a more extensive discussion of the link between social accounting matrices and AGE models, see Hanson and Robinson (1991) and Reinert and Roland-Holst (1992).

AGE model. Consider first the market-clearing conditions for tradeable commodities (TC):

$$QO(i,s) = \sum_{s\varepsilon R} QS(i,r,s), \quad \forall i\varepsilon TC;\ r\varepsilon R. \tag{1}$$

This states that the total output of i in region r must be accounted for by regional sales. Multiplying both sides by producer prices, we obtain:

$$VOA(i,r) = \sum_{s\varepsilon R} VSA(i,r,s). \quad \forall i\varepsilon TC;\ r\varepsilon R. \tag{2}$$

This highlights a fundamental point about accounting equations in an AGE model. They can always be expressed in terms of value flows, evaluated at appropriate prices.

Once commodity i from region r has reached market s, it must be distributed across uses, including intermediate demands in sectoral production (PC) and final demand. Here another market-clearing condition is required, namely:

$$VIM(i,r,s) = \sum_{j\varepsilon PC} VDMS(i,j,r,s) + VHMS(i,r,s), \quad \forall i\varepsilon TC;\ r,s\varepsilon R. \tag{3}$$

Market-clearing conditions for nontradeable endowment commodities (EC) are also evaluated at domestic market prices. The value of the total availability of endowment i in region r is denoted VOM(i,r), whereas the value of demands for i in the production of j is given by VDM(i,j,r), so the market-clearing condition becomes:

$$VOM(i,r) = \sum_{j\varepsilon PC} VDM(i,j,r), \quad \forall i\varepsilon EC;\ r\varepsilon R. \tag{4}$$

The next important accounting relationships in the AGE model are the zero-profit conditions, most naturally expressed in value terms at agents' prices. Here, the value of output must be exhausted by purchases of all inputs:

$$VOA(j,r) = \sum_{i} VDA(i,j,r), \quad \forall j\varepsilon PC;\ r\varepsilon R. \tag{5}$$

Equation 5 applies to all produced commodities (includes investment goods) in all regions.[5]

The next accounting relationship in the model provides for the computation of regional income. This is the most complicated expression in the entire model since it must take account of changes in tax/subsidy expenditures in all distorted markets. This may be expressed as follows:

$$\begin{aligned} Y(r) = & \sum_{i\varepsilon EC} VOA(i,r) \\ & + \sum_{i\varepsilon EC} VOM(i,r) - VOA(i,r) \\ & + \sum_{i\varepsilon TC} \sum_{j\varepsilon PC} \sum_{k\varepsilon R} (VDAS(i,j,k,r) - VDMS(i,j,k,r)) \\ & + \sum_{i\varepsilon TC} \sum_{k\varepsilon R} (VHAS(i,k,r) - VHMS(i,k,r)) \\ & + \sum_{i\varepsilon TC} \sum_{k\varepsilon R} (VIM(i,k,r,) - VIW(i,k,r)) \\ & + \sum_{i\varepsilon TC} \sum_{k\varepsilon R} VSW(i,r,i) - VSA(i,r,k)). \end{aligned} \tag{6}$$

The first right-hand-side (RHS) component of equation 6 captures factor payments, that is, endowment income, at household agents' prices, in each region. Note that all such income earned within a region accrues to households in that same region. Cross-ownership of factors could be introduced if data were available.

The second RHS term captures the revenue collected through income taxes in r. This may be rewritten in terms of an explicit *ad valorem* tax rate, $\tau(i,r)$, by noting that the household's supply price of endowment i is given by:

$$PS(i,r) = (1 - \tau(i,r))PM(i,r) = TS(i,r)PM(i,r),$$

so that:

$$\begin{aligned} VOM(i,r) - VOA(i,r) &= [(1 - TS(i,r))]PM(i,r)QS(i,r) \\ &= \tau(i,r)PM(i,r)QS(i,r). \end{aligned} \tag{7}$$

Thus, the fiscal implications of all tax/subsidy programs may be captured by comparison of the value of a given transaction at agents' vs. market (or market vs. world) prices. In this manner, equation 6 also captures the revenue from commodity taxes paid by firms and households, import duties, and export/production taxes.

Note that any of the value discrepancies in a given region may arise due to quantitative restrictions instead of taxes. For example, in the case of a quota on imports of i into s from r:

$$VIM(i,r,s) - VIW(i,r,s) = (TT(i,r,s) - 1)\ PIW(i,r,s)QIW(i,r,s) > 0, \tag{8}$$

which represents the associated quota rents. In this instance, QIW(i,r,s) is exogenous and TT(i,r,s) is endogenous. Again, these quota rents are

[5]This condition also applies to the provision of international transport services.

assumed to accrue to the region administering the quota.

Because most economies are heavily distorted, a global consistency check is important to ensure that all rents and tax and subsidy payments have been captured. Equations 2-6, coupled with the exhaustion of income on final demand, imply that one of the accounting equations is redundant. This is Walras's Law. It is simply an implication of tracking flows through the economy in an exhaustive manner. The centrality of Walras's Law in AGE analysis is just another manifestation of the importance of social accounting in this line of work.

The equation omitted in this article's model is the market-clearing condition forcing global savings to equal global investment. Households are assumed to purchase a homogeneous savings commodity. The price of this commodity also serves as the numeraire in this model. Equilibrium in other markets implies equality of global savings and investment, which provides an important check on the model's consistency. Errors in logic and/or implementation invariably show up here when such a model is first implemented empirically. Such a consistency check is not available in partial equilibrium models.

A general equilibrium framework should not preclude selective partial equilibrium (PE) analyses. Indeed, many problems are best addressed in a PE framework. However, a general equilibrium framework subsequently specialized to a PE model forces precision in PE assumptions. This discipline can result in stronger partial equilibrium analyses, because the researcher is absolutely clear about what is left out.

Consider how equations 2-6 would be altered to obtain a "typical" partial equilibrium model of agricultural trade. Equation 2 the market-clearing conditions for tradeable commodities, determines equilibrium world prices for food and nonfood commodities alike. If a partial equilibrium model is to exogenize nonfood prices, then the nonfood market-clearing conditions must be dropped. Partial equilibrium models also treat income as an exogenous variable. Upon fixing Y, we must eliminate equation 6.

Equation 5 poses a puzzle for the PE specialization. These zero-profit conditions serve to determine sectoral output in general equilibrium. Having fixed nonfood prices, it hardly makes sense to constrain nonfood sectors to operate at zero profits. Thus, in specializing equations 2-6 to a multiregion, partial equilibrium model, I omit equation 5 for the nonfood sectors and explicitly fix nonfood output levels at their initial values. The derived demand for farm products in nonfood uses will now show no expansion effect in the nonfood sectors' intermediate demands for food. (We cannot eliminate these nonfood uses of farm products altogether without destroying the commodity balance as described by equations 2 and 3.)[6]

Finally, turn to the market-clearing conditions for the endowment commodities (equation 4). These primary-factor, market-clearing conditions link individual sectors, thereby constraining their general equilibrium supply response. However, in partial equilibrium, I assume that the opportunity cost of labor and capital in agriculture is exogenous over the medium term. Implementation of this assumption leads to the elimination of equations in equation 3 that are associated with market clearing for the regional endowments of labor and capital services. However, without some sector-specific rigidities, partial equilibrium supply response would be infinitely elastic (assuming constant returns to scale at the industry level). Thus, farmland is treated as a sector-specific agricultural input, thereby "tying down" longrun supply response.

These partial equilibrium assumptions may be summarized as follows: nonfood output levels and prices are exogenous, income is exogenous, and nonland primary factor rental rates are exogenous. They will be invoked to illustrate the difference between partial and general equilibrium analyses of trade liberalization.

While the accounting relationships (equations 2-6) are most conveniently expressed in value terms, it is attractive to write the behavioral component of the model in terms of percentage changes in prices and quantities. Indeed, it is these percentage changes that we are usually most interested in. Expressing this nonlinear model in percentage changes does not preclude a solution to the true nonlinear problem. Solution of nonlinear AGE models via a linearized representation (Pearson,

[6]This would seem to be an important distinction between the partial equilibrium model developed here, and the traditional PE models of agricultural trade. In the latter case, nonfood intermediate demands are often lumped together with final demand. This can be an important distinction if either the price responsiveness of these two demands is quite different, or policies influencing the two sources of demand are different.

1991)[7] involves successively updating the value-based coefficients via the formula: $dV/V = d(PQ)/PQ = p + q$, where the lower case p and q denote percentage changes in price and quantity.

Linearization of accounting equations (2-6) involves totally differentiating them so they appear as appropriately weighted price and quantity changes. For example, the tradeable market-clearing condition becomes:

$$QO(i,r)qo(i,r) = \sum_{s\varepsilon R} QS(i,r,s)qs(i,r,s), \tag{9}$$

where the lowercase variables are again percentage changes. Multiplying both sides by the common price, PS(i,r), yields equation T1 (table 1). Here, the coefficients are now in value terms. It is never necessary to actually compute price and quantity levels (P and Q) under this approach.

The next two equations in table 1 are also market-clearing conditions and have a similar structure. However, the common price is now a domestic market price, and so the value weights are evaluated at market prices, rather than agents' prices.

Equation T4 is the zero-profit condition. Since firms are assumed to maximize profits, the quantity changes drop out when equation 5 is totally differentiated in the neighborhood of an optimum. This leaves an equation relating input prices to output prices, where these percentage changes are weighted by values at agents' prices.

The final equation, T5, in table 1 is quite lengthy in linearized from. However, it is also rather instructive. Its interpretation is aided by considering the following equations, which link commodity prices in the model:

$$ps(i,r) = pme(i,r) + to(i,r); \qquad \forall i\varepsilon EC, r\varepsilon R \tag{10}$$

$$pde(i,j,r) = pme(i,r) + td(i,j,r); \qquad \forall i\varepsilon EC, r\varepsilon R \tag{11}$$

$$pds(i,j,r,s) = pms(i,j,r,s) + tds(i,j,r,s); \qquad \forall i\varepsilon TC, j\varepsilon PC; r,s\varepsilon R \tag{12}$$

$$phs(i,r,s) = pms(i,r,s) + ths(i,r,s); \qquad \forall i\varepsilon TC; r,s\varepsilon R \tag{13}$$

$$pms(i,r,s) = pcif(i,r,s) + tm(i,r,s) + [1 - \delta(r,s)]tv(i,s); \qquad \forall i\varepsilon TC; r,s\varepsilon R \tag{14}$$

[7]This type of nonlinear solution procedure is now the default option in GEMPACK. For a complete comparison of the linearized and levels approaches to AGE modeling, the reader is referred to Hertel, Horridge, and Pearson (1992).

$$ps(i,r) = pfob(i,r,s) + ts(i,r,s) + [1 - \delta(r,s)]tx(i,r); \qquad \forall i\varepsilon TC; r,s\varepsilon R. \tag{15}$$

The second (and third) terms on the right-hand-side of equations 10-15 represent percentage changes in the level of policy interventions in various markets, expressed as one plus the *ad valorem* equivalent of the distortion in question. In other words, $to(i,r) = dTO(i,r)/TO(i,r)$, where $TO(i,r) = PS(i,r)/PME(i,r)$. When these distortions are treated as *exogenous*, unless they are shocked, price linkage is complete.

The interventions in equations 10-15 are as follows: to(i,r) denotes income taxes, td(i,j,r) refers to primary factor taxes on firms, tds(i,j,r,s) and ths(i,r,s) are commodity taxes, tm(i,r,s) and tv(i,s) are import duties where the latter is source-generic, and ts(i,r,s) and tx(i,r) are the destination-specific and destination-generic sales (export) taxes [$\delta(r,s)$ is the Kronecker delta]. There is one "price linkage" omitted from equations 10-14, namely the f.o.b-c.i.f. link. This gap depends on the price of transport services, as follows:

$$VIW(i,r,s)pcif(i,r,s) = VSW(i,r,s)pfob(i,r,s) + VTW(i,r,s)pt. \tag{16}$$

The rate of change in *pt* is determined by the cost of transport services exports from each region.

Having established the linkage between prices in this model, consider the effect of omitting some component of equation T5, say, income taxes. How will this affect our welfare analysis of trade policy reform? Given the presence of income taxes in the initial equilibrium data base, $VOM(i,r) > VOA(i,r)$, if the experiment in question does not alter the *rate* of income taxation, then $to(i,r) = 0$ and $\alpha = ps(i,r) = pme(i,r)\ \forall i\varepsilon EC$. This means the two terms in square brackets [•] (equation T5, second RHS term) change at the same rate. If this change is positive, then omission of this term will lead to an understatement of income tax revenues and a subsequent understatement of disposable income and household welfare in the new equilibrium. In sum, even when distortions are not affected by a given policy experiment, it is important to acknowledge this presence in the economy if an accurate welfare analysis is to be provided.

Behavioral Equations

Firms are assumed to maximize profits subject to a separable, constant returns-to-scale technology. This pattern of separability is dictated by the limited availability of common parameters across diverse regions of the world. In particular, value-

Table 1—Accounting equations expressed in linearized form

(T1) $VOA(i,r)qo(i,r) = \sum_{s \varepsilon R} VSA(i,r,s)qs(i,r,s)$	$\forall i \varepsilon TC\ r \varepsilon R$
(T2) $VIM(i,r,s)qs(i,r,s) = \sum_{j} VDMS(i,j,r,s)qds(i,j,r,s)$	$\forall i \varepsilon TC;\ r,s \varepsilon R$
(T3) $VOM(i,r)qo(i,r) = \sum_{j} VDM(i,j,r)qde(i,j,r)$	$\forall i \varepsilon EC;\ r \varepsilon R$
(T4) $VOA(j,r)ps(j,r) = \sum_{i \varepsilon EC} VDA(i,j,r)pde(i,j,r) + \sum_{i \varepsilon TC} VDA(i,j,r)pd(i,j,r)$	$j \varepsilon PC;\ r \varepsilon R$
(T5) $Y(r)y(r)$	$\forall r \varepsilon R$

$$
\begin{aligned}
&= \sum_{i \varepsilon EC} VOA(i,r)[ps(i,r) + qo(i,r)] \\
&+ \sum_{i \varepsilon EC} (VOM(i,r)[pme(i,r) + qo(i,r)] - VOA(i,r)[ps(i,r) + qo(i,r)]) \\
&+ \sum_{i \varepsilon EC} \sum_{j \varepsilon PC} (VDA(i,j,r)[pde(i,j,r) + qde(i,j,r)] - VDM(i,j,r)[pme(i,j,r) + qde(i,j,r)]) \\
&+ \sum_{j \varepsilon PC} \sum_{i \varepsilon TC} \sum_{s \varepsilon R} (VDAS(i,j,s,r)[pds(i,j,s,r) + qds(i,j,s,r)]) \\
&+ \sum_{i \varepsilon TC} \sum_{s \varepsilon R} (VHAS(i,s,r)[phs(i,s,r) + qhs(i,s,r)] - VHMS(i,s,r)[pms(i,s,r) + qhs(i,s,r)]) \\
&+ \sum_{i \varepsilon TC} \sum_{s \varepsilon R} (VSW(i,r,s)[pfob(i,r,s) + qs(i,r,s)] - VSA(i,r,s)[ps(i,r) + qs(i,r,s)]) \\
&+ \sum_{i \varepsilon TC} \sum_{s \varepsilon R} (VIM(i,s,r)[pms(i,s,r) + qs(i,s,r)] - VIW(i,s,r)[pcif(i,s,r) + qs(i,s,r)])
\end{aligned}
$$

added is assumed separable from intermediate input demands. Furthermore, within the intermediate input structure, firms are assumed to first decide on the optimal sourcing of imports, thereafter substituting composite imports for domestic production. This is the so-called Armington approach. Finally, composite intermediate inputs and value-added are combined in fixed proportions.

This technology is reflected in the equations provided in table 2. The first equation, T6, describes changes in the demand for endowment commodities (qde) due to substitution and expansion effects. Linear homogeneity in value-added implies that qde increases at the same rate as value-added (qva) if relative prices are unchanged. Changes in the *composition* of value-added are governed by the elasticity of substitution (σ_{VA}), applied to the changes in the price of individual components relative to their composite. The latter is obtained via equation T7.

Equation T8 describes the demand for intermediate inputs, by source, with $\delta(r,r) = 1$ and $\delta(r,s) = 0$ when $r \neq s$. This permits distinction between domestic sourcing and foreign sourcing. The former depends only on the relative price of domestic goods vs. composite imports [pdm(i,j,s) − pds(i,j,s,s)], weighted by the share of imports (θ_m) and the appropriate substitution elasticity. Import sourcing is conditional on the overall level of imports (qdm) as well as relative prices of imports from different sources. The elasticity of substitution among imports, σ_m, governs the responsiveness of import composition. Like the demand for domestic intermediate goods, qdm depends on total intermediate demand (qd) and substitution between domestic and import goods.

Equations T10 and T11 create composite price indices for imports and the composite intermediate good. Finally, equation T12 reflects the assumption of fixed coefficients in the derived demand for intermediate goods and value-added. The overall activity level in each sector is determined by the zero-profit condition given in equation T4.

The linearized representation of producer behavior (table 2) facilitates intuition regarding the effects of a trade policy shock. Consider, for example, a

Table 2—Producer behavior in the model

(T6) $qde(i,j,r) = \sigma_{VA}(j)[pva(j,r) - pde(i,j,r)] + qva(j,r)$	$\forall j\varepsilon PC,\ r\varepsilon R$
(T7) $[\sum_{i\varepsilon EC} VDA(i,j,r)]pva(j,r) = \sum_{i\varepsilon EC} VDA(i,j,r)pde(i,j,r)$	$\forall j\varepsilon PC,\ r\varepsilon R$
(T8) $qds(i,j,r,s) = \delta(r,s)\,\{qd(i,j,s) + \theta_m(i,j,s)\,\sigma_D(i)\,[pdm(i,j,s) - pds(i,j,s,s)]\} + [1 - \delta(r,s)]\,\{qdm(i,j,s) + \sigma_m(i)\,[pdm(i,j,s) - pds(i,j,r,s)]\}$	
(T9) $qdm(i,j,s) = qd(i,j,s) + [1 - \theta_m(i,j,s)]\,\sigma_D(i)[pds(i,j,s,s) - pdm(i,j,s)]$	$\forall i\varepsilon TC,\ j\varepsilon PC,\ s\varepsilon R$
(T10) $pdm(i,j,s) = \sum_{r\neq s} \theta(i,j,r,s)\, pds(i,j,r,s)$	$\forall i\varepsilon TC,\ j\varepsilon PC,\ s\varepsilon R$
(T11) $pd(i,j,r) = \theta_m(i,j,r)pdm(i,j,r) + [(1 - \theta_m(i,j,r)]pds(i,j,r,r)$	$\forall i\varepsilon TC,\ j\varepsilon PC,\ s\varepsilon R$
(T12) $qva(j,r) = qd(i,j,r) = qo(j,r)$	$\forall i\varepsilon TC,\ j\varepsilon PC,\ r\varepsilon R$

Definitions:
$\theta(i,j,r,s) \equiv VDAS(i,j,r,s)/\sum_{r\neq s} VDAS(i,j,r,s)$, and $\theta_m(i,j,s) \equiv \sum_{r\neq s} VDAS(i,j,r,s)/VDA(i,j,s)$.

reduction of the bilateral tariff on imports of i from r into s ($tm(i,r,s) < 0$). This lowers pms(i,r,s), and hence pds(i,j,r,s), via price linkage equations 14 and 12. Firms immediately substitute away from competing imports according to (T8). Also, the composite price of imports falls via (T10), thereby increasing the aggregate demand for imports through (T9). Cheaper imports lower the composite price of intermediates through (T11), which causes excess profits at current prices, via (T4). Provided the zero-profit condition is included in the model, this induces output to expand, which in turn generates an expansion effect via (T12). Of course, in a partial equilibrium model whereby nonfood sectors' activity levels are exogenous, the latter effect will only be present in the case of the food sectors.

The expansion effect induces increased demands for primary factors of production via (T6). In the partial equilibrium closure, labor and capital are assumed to be forthcoming in perfectly elastic supply from the nonfood sectors, so pde(i,j,r) is unchanged for i = labor, capital. However, in the general equilibrium model, this expansion generates an excess demand via the endowment market-clearing condition (T3), thereby bidding up the prices of these factors, and transmitting the shock to other sectors in the liberalizing region.

Now turn to region r, which produces the goods for which tt(i,r,s) is reduced. Equation T2 may be used to determine the implications for total sales of i from r to s, given the responses of individual production sectors ($j\varepsilon PC$) and the aggregate household to the tariff shock. Equation T1 dictates the subsequent implications for total output: qo(i,r). (That is, this market-clearing condition must have been eliminated, and ps(i,r) fixed, under the PE closure.) At this point, the equations in table 2 again come into play, with (T12) transmitting the expansion effect back to intermediate demands and to region r's factor markets.

Households are treated as utility-maximizing entities, resulting in the following set of behavioral equations, expressed in linearized form:

$$qh(i,r) = \sum_{k\varepsilon HC} \eta_P(i,k,r)ph(i,k) + \eta_I(i,r)y(r) \quad \forall i\varepsilon HC;\ r\varepsilon R. \tag{17}$$

Here, $\eta_P(\cdot)$ is an uncompensated cross-price elasticity of demand, and $\eta_I(\cdot)$ is an income elasticity of demand. These elasticities are functions of consumers' underlying preference parameters as well as the value flows, VHA(i,r). The precise nature of this relationship depends on the form of utility function assumed.

In this article, commodities have been aggregated so that consumers purchase three consumption goods and savings. Given the highly aggregate nature of this example, I have chosen to use a Cobb Douglas utility function. In this special case, $\eta_P(i,i,r) = -1$, $\eta_P(i,j,r) = 0$, and $\eta_I(i,r) = 1$. However, in more general cases, η_P and η_I will vary with the value flows (that is, with changing prices and quantities).

Aggregate welfare in each region is measured in terms of utility. Given the Cobb Douglas assumption, changes in utility are derived as follows:

$$u(r) = \sum_{i \varepsilon HC} [VHA(i,r)/Y(r)]qh(i,r). \tag{18}$$

These utility changes may be converted to equivalent variations based on information about income levels in initial equilibrium.

The sourcing of consumer demands, qhs(i,r,s), in this model follows precisely the same approach as for firms. Thus, equations T8-T11 are repeated for the three traded commodities. As noted above, savings is a homogeneous product, supplied by the global banking sector.

A global banking sector is established to intermediate between global savings and investment. This activity assembles a fixed portfolio of regional investment goods [qo(capital goods,r)] and sells shares in this homogeneous savings commodity to households in all regions [qh(savings, r)]. As noted above, equality of global supply and demand for savings is implied by Walras's Law, and offers a consistency check on the entire model.

The other global activity required in this model is international transport services. These services are provided via a Cobb Douglas production function that utilizes transport services exports from each region. A zero-profit condition, analogous to equation 5, guarantees that the full cost of international transportation services is reflected in the price changes, pt, which determine international transport margins via equation 16.

Results of Two Experiments

Experiment 1: Multilateral, Multicommodity Liberalization of Non-CAP Trade Policies. The first experiment with this highly aggregated model involves removal of all non-CAP farm and food policy distortions, as well as tariffs and all export taxes on mining and manufacturing products.[8] Because the CAP is left in place, it insulates the EC's food sector. Specifically, a variable import levy maintains a constant relative price for domestic and imported food, while a variable export subsidy fixes the level of aggregate food output.

Table 3 reports the difference between partial and general equilibrium model predictions of the subsequent change in food products trade.[9] (Diagonal elements refer to domestic sales.) As discussed above, the partial equilibrium model is obtained as a special case of the full general equilibrium model by fixing (a) the rental rates for labor and capital, (b) income, and (c) nonfood tradeable output and prices in all regions. I focus here on the differences in the PE and GE outcomes to draw attention to the added value obtained by analyzing this experiment using the full general equilibrium model.

The differences in table 3 are reported in two forms: volumes and percentage changes. Volumes are measured in 1988 U.S. dollars, evaluated at agents' prices in initial equilibrium. They are not comparable across rows (that is, across suppliers). Thus, no column sum is provided. However, the row sum (summation across destinations) equals the total difference in predicted post-liberalization output in each of the regions owing to the use of a partial equilibrium model to analyze this multilateral trade liberalization question. These discrepancies are also reported (in parentheses) as a percentage of the initial quantity sold to each destination.

Consider first the entries in the column headed "total." Positive numbers indicate that the partial equilibrium analysis of this cross-sectoral, multilateral shock overstates the *level* of food output in the liberalized environment in the case of New Zealand, Japan, Korea, ASEAN, and ROW (rest-of-the-world) countries. Negative entries indicate that the PE approach understates the *level* of liberalized food output in other cases, namely Australia, Canada, and the United States. (The CAP insulates EC agriculture so that its food output is fixed in both experiments.) Note, however, that the sign of these differences does not indicate whether the new output level is above or below its initial equilibrium value. This information is conveyed by the presence or absence of an asterisk. In those cases where general (and partial) equilibrium food output falls under multilateral liberalization (Australia, Canada, Japan, and Korea), an asterisk appears. Consequently, an asterisk appended to a negative entry implies that the partial equilibrium model overstates the change in output. Since this change is negative, the PE model understates the new *level* of food output in these regions. On the

[8]Details on the initial policy interventions are provided in Dee and others (1992), and Jomini and others (1991). They are not present in the residual region (ROW), so this liberalization experiment only applies to the non-ROW regions. Agricultural interventions are drawn from the OECD's PSE data base. Market price support is achieved via border interventions while producer payments are introduced as output subsidies.

[9]The model is implemented using the GEMPACK software package (Codsi and Pearson (1988); Pearson 1991)). A copy of the algebraic code and a complete, electronic appendix is available from the author upon request. All results in this section have been independently verified by Karen Chyc.

Table 3—Difference in predicted farm and food sales volumes due to partial equilibrium assumptions in the presence of multilateral trade liberalization[1,2]

Source	Australia	New Zealand	Canada	United States	Japan	Korea[1]	European Community	ASEAN	Rest of the World	Total	Nonfood Manufacturers[3]	Services[3]
Australia	−212*	−15	−26	−170	−182	−7*	−144*	−55	−311*	−1127*	2017	−1316
	(−0.5)	(−8.0)	(−9.6)	(−14.5)	(−6.7)	(−1.8)	(−7.4)	(−4.6)	(−6.9)	(−2.3)	(1.4)	(−0.4)
New Zealand	17	177	15	33	15*	−0*	−0*	49	57*	366	1374	73
	(5.9)	(1.8)	(12.1)	(4.9)	(3.0)	(−0.5)	(−0.0)	(12.0)	(2.7)	(2.4)	(5.0)	(0.1)
Canada	−0*	−0*	−598*	−121*	−36*	−2*	−29*	−1*	−144*	−937*	−4685	−5869
	(−0.8)	(−3.7)	(−0.9)	(−3.9)	(−2.0)	(−1.0)	(−3.1)	(−0.9)	(−2.6)	(−1.2)	(−1.5)	(−1.0)
United States	2*	−0*	18*	−1427*	183	−113	−87*	12*	−118*	−1530	37256	−16018
	(1.7)	(−0.1)	(0.5)	(−0.3)	(2.0)	(−6.3)	(−1.7)	(1.0)	(−0.5)	(−0.3)	(1.5)	(−0.3)
Japan	0	−0	−0	−11	1042*	−1*	−9	0*	−16	1003*	−55308	−2187
	(1.2)	(−3.4)	(−0.9)	(−4.4)	(0.2)	(−3.3)	(−5.0)	(0.3)	(−2.9)	(0.2)	(−3.4)	(−0.0)
Korea	0*	0*	0*	5*	12*	936*	0*	1*	10*	969*	−13551	1435
	(2.6)	(2.8)	(1.9)	(2.2)	(0.7)	(2.0)	(0.6)	(1.4)	(1.6)	(1.9)	(−8.0)	(0.8)
European Community	1	−2	−11	−163	−67	−7*	2069*	3	−1822*	0	13710	−7851
	(0.2)	(−4.3)	(−2.0)	(−6.5)	(−3.6)	(−1.9)	(0.2)	(0.4)	(−3.0)	(0.0)	(0.4)	(−0.1)
ASEAN	22	2	8	28	25*	−1*	−72	3820*	119	3953	−8265	2405
	(5.6)	(2.9)	(2.7)	(0.9)	(0.8)	(−0.1)	(−1.7)	(4.0)	(1.6)	(3.4)	(−5.5)	(1.7)
Rest of the World	37	8	90	535	370	32	461	166	1350	3052	19642	1835
	(9.3)	(7.0)	(6.1)	(4.8)	(6.6)	(4.2)	(1.2)	(6.3)	(0.1)	(0.4)	(0.7)	(0.0)

[1]Difference = Partial equilibrium prediction − General equilibrium prediction.
[2]Volumes are defined as the quantity that may be purchased for one dollar in initial equilibrium at agent prices.
[3]Partial − General equilibrium prediction = − General equilibrium prediction since the partial equilibrium framework holds nonfood output constant, by assumption.
*Indicates that liberalized food sales are lower than those in initial equilibrium. Thus, a negative entry in the total column, for example, indicates that partial equilibrium output falls by more than general equilibrium output. An asterisk accompanying a positive entry means that PE output falls by less than the GE estimate.

other hand, the combination of a positive entry and no asterisk means that the PE model overstates both the increase in output *and* its new level. Applying this logic to the total column subjects the partial equilibrium model to charges of overshooting the change in food output for Australia, New Zealand, Canada, ASEAN, and ROW countries. In the case of the United States, Japan, and Korea, the partial equilibrium model understates the change in food output owing to non-CAP liberalization.

These discrepancies between the PE and GE results stem from two sources. First, the partial equilibrium model fails to acknowledge the supply response constraints imposed by fixed factor endowments. Thus, the general equilibrium food supply response is smaller than its partial equilibrium counterpart, with the magnitude of this discrepancy being roughly proportional to the share in endowments of mobile primary factors used in agriculture. The food sector's supply increase in New Zealand, ASEAN, and ROW countries is constrained in general equilibrium, and the partial equilibrium framework exaggerates the degree to which food output is likely to expand under multilateral liberalization.

This argument also works in reverse. The presence of general equilibrium factor market constraints tends to dampen the output reduction in economies where the decline in firm output is sufficient to depress labor and capital prices. This is reflected in the cases of Australia and Canada, where food output falls following liberalization and there is a negative entry in table 3. In the remaining cases, this line of reasoning is violated. In other words, the GE changes are larger and the PE model understates the change in output.

The second source of divergence between the PE and GE results explains why the PE model might understate GE changes. Recall that the liberalization experiment involves not only food liberalization, but also shocks to mining and manufacturing trade policies. In particular, tariffs and export taxes/subsidies are removed. These nonfood shocks are not reflected in the PE model results, as that framework assumes that all nonfood output and price levels are fixed. Thus, to the extent that manufacturing trade liberalization has an impact on the pattern of food output and sales, this will also cause a divergence in the PE and GE predictions for the food sector.

The last two columns in table 3 report the *negative* of the total and percentage changes in volume of output in nonfood manufacturing and mining output, and in services. (The partial equilibrium prediction is zero, so this entry is $(0 - \beta)$ where β is the GE model's predicted change.) The very strong increase (8 percent) in GE manufacturing

output in Korea explains why the PE model underpredicts the decline in Korean food output under non-CAP liberalization. As manufacturing activity expands, the cost of labor and capital to the food sector rises, thereby forcing a further decline in output. The same is true of Japan. The United States also shows a PE food response lower than its GE counterpart. Here, food output is projected to rise, and nonfood manufacturing output falls. Consequently, scarce factors are released for use in agriculture, such that the U.S. general equilibrium food supply response is greater than in partial equilibrium.

Table 3 also breaks down the sources of these discrepancies in sales predictions. These are proportionately much larger than the output discrepancies. (With the exception of Australia, the largest absolute changes are along the diagonal, because domestic sales represent the bulk of most regions' total output.) The most extreme compositional change is provided by EC food sales. Here, PE and GE predictions are constrained to be equal in total, since the CAP insulates output in both cases. Yet, the PE and GE results exhibit sizable discrepancies in composition. In particular, the PE model overpredicts domestic food sales in the EC by $2 billion. To understand this, note that by fixing (a) the price of imported food relative to domestic food, and (b) food output, the PE model effectively holds the price of domestic food paid by consumers constant. Since manufacturing prices in the EC are constant by assumption, there is no incentive for households to change their consumption mix. Indeed, with income fixed, aggregate EC food consumption is unaltered.

By contrast, in the general equilibrium multilateral liberalization experiment, EC manufacturing prices fall relative to internal food prices. Thus, households shift consumption toward nonfood items, causing domestic food sales to fall. To maintain the same level of output, the EC must increase its export subsidy. Since the bulk of initial EC food exports go to ROW countries, the largest increment of the PE-GE difference crops up there. However, on a percentage basis, EC food sales to the United States are most severely overstated by the PE experiment, a discrepancy equal to 7 percent of initial food sales from the EC to the United States.

This first experiment was chosen to highlight the inadequacy of partial equilibrium models for handling simultaneous shocks to both agriculture *and* nonagriculture. This is clearly a problem in the case of multicommodity trade negotiations, be they bilateral or multilateral. However, some trade policy shocks will involve only the food sector, in which case the partial equilibrium model is capable of providing a much better approximation.

Experiment 2: Reform of the CAP. The first experiment removed all trade distortions other than the CAP, allowing experiment 2 to estimate the impact of eliminating the CAP. In effect, this experiment estimates the additional gains to be had by including the CAP in an overall package of multilateral reforms.[10] Of course, with all other farm and food policies already removed, world food prices are now higher and the CAP is less distortionary than in the initial equilibrium.

Table 4 reports the estimated changes in food, manufacturing, and services output levels owing to reform of the CAP, for a variety of model specifications. The first set of columns are the predicted output changes based on solution of the full general equilibrium multiregion (GEMR) model. As in table 3, volumes are defined in terms of the value of production, evaluated at initial equilibrium agents' prices, so they are not additive across rows. Nevertheless, they do give an idea of the relative magnitude of the changes induced by CAP reform. The first column, headed F (food), shows that the quantity of EC food production falls by $86.2 billion, while other regions increase food output. The United States and ROW countries experience the largest absolute increases, while the percentage increase (parentheses) is largest for New Zealand.

The columns under GEMR headed M and S report the changes in manufacturing and services output as a result of CAP reform. The entries here are opposite in sign, and their sum is similar in absolute value to the food output changes. This reflects the fact that each economy has finite resource base. If more food is to be produced, this will come at the expense of other activities. The increase in EC nonfood output is quite substantial, reflecting the fact that the CAP represents a significant distortion of the nonfood economy.

The second set of columns (2) in table 4 corresponds to the partial equilibrium multiregion model (PEMR) introduced above. Here, nonfood prices and output are fixed by assumption, hence the zeros under the M and S columns. Also, income and rental rates for labor and capital are fixed. As before, the latter assumption exaggerates the food sector's supply response and thus leads to a tendency to exaggerate output changes. This is most pronounced in the case of New Zealand,

[10]See Hertel, Gehlhar, and McDougall (1992) for a detailed analysis of this experiment.

Table 4—Estimated changes in nonservice output levels following CAP reform under alternative assumptions

Region	Alternative assumptions											
	1 GEMR			2 PEMR			3 GESR			4 PESR		
	F	M	S	F	M	S	F	M	S	F	M	S
Australia	2,173	–2,084	–265	2,594	0		0	0	0	0	0	0
	(4.5)	(–1.6)	(–0.1)			0						
New Zealand	2,754	–1,826	–536	4,703	0	0	0	0	0	0	0	0
	(15.7)	(–7.0)	(–1.2)									
Canada	2,345	–1,780	–171	2,409	0	0	0	0	0	0	0	0
	(3.8)	(–0.6)	(–0.0)									
United States	11,740	–7,975	–147	12,296	0	0	0	0	0	0	0	0
	(2.3)	(–0.3)	(–0.0)									
Japan	1,104	–954	–34	998	0	0	0	0	0	0	0	0
	(0.4)	(–0.1)	(–0.0)									
Korea	91	–146	7.5	83	0	0	0	0	0	0	0	0
	(0.3)	(–0.1)	(0.0)									
European Community	–86,238	42,835	19,717	–94,194	0	0	–89,989	46,075	19,762	–97,527	0	0
	(–10.9)	(1.5)	(0.5)									
ASEAN	2,549	–2,716	–289	2,929	0	0	0	0	0	0	0	0
	(2.3)	(–1.8)	(–0.2)									
Rest of the World	24,181	–21,034	–2,304	25,109	0	0	0	0	0	0	0	0
	(3.01)	(–0.8)	(–0.1)									

GEMR = Full general equilibrium model predictions.
PEMR = Nonfood output and prices fixed; labor and capital rental rates and income fixed.
GESR = Non-EC outputs, prices, and incomes fixed.
PESR = All output levels and prices fixed except for EC food; all incomes, labor, and capital rental rates fixed.

where CAP reform generates a strong demand for food output. However, this overshooting effect is also evident in the EC.

The final two groups of columns in table 4 refer to predictions based on single-region models of the EC alone. They are attained by fixing all output levels, prices, and incomes in non-EC regions.[11] This is reflected in the predominance of zeros in all three columns. The results under GESR are based on a single-region, general equilibrium model whereby EC income, nonfood output, and domestic prices are endogenous. This type of model has been a popular one for analyzing the economywide effects of unilateral trade liberalization of farm and food policies.[12] A comparison of entries in the EC row of table 4 shows that this framework is somewhat more successful than PEMR in predicting the likely changes in food output. However, it too overshoots for both food and nonfood output changes.

The fourth set of columns, headed PESR, illustrate the value of a single-region, partial equilibrium model for estimating the effect of CAP reform on the EC food sector. The estimated change in food output using this simple model provides a fair approximation to the GEMR solution. Of course, the impetus for reform of the CAP has come from producers in other countries who feel that their output levels have been adversely affected. Given this interest in the international implications of farm policies, it has become common to analyze such unilateral agricultural policy shocks in a multilateral framework. But why hasn't this line of reasoning been carried to its logical conclusion, namely the displacement of models of the PEMR class with GEMR models? Certainly the changes in nonfood output displayed in column 1 are comparable in absolute magnitude.

The answer to this question lies in the fact that the percentage changes associated with the numbers in the M and S columns of table 4 (see parentheses) are much smaller than those pertaining to the food sector. Until recently, nonfood groups have taken little notice of food policies. Thus the U.S. Farm Bill is largely left to the farm lobby (subject to certain budget constraints) and the debate over agricultural trade reform was long left to the GATT's Negotiating Group on Agriculture. However, the stumbling of the Uruguay Round owing to an unresolved agricultural dispute has revealed yet again the difficulty of achieving farm policy reform without nonfarm input. Outside pressure and some prospect for offsetting gains must be brought to bear on this process.

[11]Note, however, that fixing output levels does not eliminate the price responsiveness of imports in the rest of the world, as governed by equations T8-T11.

[12]For U.S. applications, see Kilkenny and Robinson (1990), as well as the Hertel, Thompson, and Tsigas (1989), and Robinson, Kilkenny, and Adelman (1989) papers in Stoeckel and others (eds.). That volume also contains similar applications for Australia, Germany, the EC, Korea, and Japan.

The difference between negotiating over agricultural trade in isolation and negotiating in the context of a broader agenda is evidenced in the difference between columns grouped under headings 1 and 2 in table 4. If negotiators look only at agriculture (PEMR), it is clear that reform of the CAP translates into a big cut in EC food output "in favor" of the other regions. When one looks at the GEMR results, it is clear that (a) good things can happen in the EC, that is, nonfood producers become more competitive and output rises, and (b) the purported output "gains" in the other regions are perhaps less dramatic then they might first appear, as they come at the expense of diminished nonfood output. Indeed, the total volume of U.S. exports to the EC actually falls when the CAP is reformed (Hertel, Gahlhar, and McDougall, 1992) since the EC is more important as an outlet for U.S. manufacturers (sales of which decline to the EC) than for food (sales of which rise to the EC). Nonfood interest groups have not paid more attention to agricultural policies because most models/analyses of these policies do not report variables of interest to the nonfood sector. By quantifying these economywide costs, we can contribute to the mobilization of a broader constituency for CAP reform.

Of course, the ultimate advantage of the AGE framework lies in its ability to trace everything back to households. While I have not emphasized the welfare dimension of these experiments, the ability to summarize results in the form of changes in well-being of people is a powerful tool. It goes a long way towards debunking the mercantilist arguments that have confounded those seeking to reform international trade.

Summary and Conclusions

This article has highlighted the importance of accounting equations in multiregion, applied general equilibrium analysis. General equilibrium modelers are social accountants. This exhaustive accounting has several important benefits. First of all, the absence of "leakages" assures us that welfare analyses based on the model will be complete. Furthermore, by tracking everything back to household utility, welfare analysis is also simplified. A second benefit of this closed system of social accounts is the consistency check offered by Walras' Law. This is an invaluable tool in verifying the internal consistency of an AGE model, and it is not available to partial equilibrium modelers. Finally, by exhaustively documenting all economic linkages, however small, the AGE modeler who chooses to conduct partial equilibrium analysis is able to make explicit the precise nature of the PE assumptions to be employed. In short, experience with AGE models can make you a stronger PE modeler.

To illustrate the differences between partial and general equilibrium analysis, a simple nine-region, three-commodity AGE model was used to analyze two policy experiments under a variety of assumptions. The first experiment involved liberalization of both food and nonfood policies. In this case, the partial equilibrium model was substantially in error in a number of its predictions about the pattern of changes in food production and trade. This was directly attributable to the absence of any mechanism for incorporating nonfood shocks into a partial equilibrium model of farm and food trade.

The second experiment involved a food-specific shock, namely reform of the EC's Common Agricultural Policy. Here, a partial equilibrium approach was quite successful in approximating the general equilibrium changes in food output. However, by remaining silent on the likely effect on nonfood output, the PE model missed an important part of the story, namely the fact that the CAP represents a substantial "tax" on EC nonfood exports. By endogenizing nonfood activity, *AGE analysis serves as a continual reminder that ultimately agricultural and nonagricultural interests in trade cannot be separated.* The policy relevance of this point cannot be overstated. The avenue to substantial global agricultural reform requires involvement on the part of nonagricultural interest groups. A dismantling of the wall of protection and subsidies erected around the farm and food sectors in many industrialized economies is unlikely without pressure from these quarters.

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Alternative Forms for Production Functions of Irrigated Crops

Michael R. Moore, Noel R. Gollehon, and Donald H. Negri

Abstract. *The output elasticities of irrigation water are highly inelastic for every crop, indicating that reductions in water supply would have relatively small effects on crop production. This article reports estimates of Cobb-Douglas and quadratic production functions for 13 irrigated crops in the 17 Western States. Returns to scale, the output elasticity of irrigation water, and the marginal rate of substitution between water and land are estimated for each crop. J-tests, used to test statistically which, if either, functional form is a correct specification, do not reject the Cobb-Douglas specification for four crops (barley, grain sorghum, potatoes, and rice) and do not reject the quadratic specification for three crops (cotton, dry beans, and potatoes).*

Keywords. *Production function, irrigation, output elasticity, model specification test, water conservation, Western United States.*

As western water institutions adopt water management objectives to replace their traditional irrigation development mission, research on water use in irrigated agriculture takes on a new dimension. Understanding the relationship between crop yield and water applications has contributed to public-sector irrigation development planning and private-sector water use decisions. Private, State, and Federal institutions, however, are now designing methods and policies to enhance the efficiency of water use in irrigation (Smith, 1989; U.S. Dept. Interior, 1987; Western Governors' Association, 1986). With increased intersectoral competition for surface-water resources and sustained mining of ground-water reserves, most irrigators in the Western United States will encounter water conservation incentives. Estimating the relationship between irrigated crop production and input use, therefore, provides an important empirical basis for assessing the impact of irrigation water conservation on agricultural output and input use.

This article presents estimates of production functions for 13 irrigated crops using two common functional forms, Cobb-Douglas and quadratic. Whereas most previous studies use localized field-experiment data, the estimates reported here are based on survey data from the 1984 Farm and Ranch Irrigation Survey (FRIS) (U.S. Dept. Commerce, 1986a) for the 17 Western States. Broad geographic and crop coverage, uniform data sources, and uniform definition of variables across crops combine to produce a comprehensive, consistent econometric analysis of irrigated production. The results establish a basis for evaluating four important water conservation alternatives: applying less irrigation water, substituting irrigation technology for water, substituting land for water, and adopting more sophisticated techniques of irrigation scheduling. By evaluating the performance of two common functional forms, the article also establishes a basis for discussing the merits of alternative functional forms for a large number of crops.

Previous Research

Research on econometrically estimated production functions for irrigated agriculture can be divided into three categories. The first category links agronomic concepts of nutrient intake, climate, and evapotranspiration with economic production analysis (for example, Yaron, 1967; Hexem and Heady, 1978). Based primarily on field-experiment data, this research estimates functions relating plant yield to water and, in some cases, fertilizer applications and weather.[1] This research concludes that polynomial response functions (square root and quadratic functions) provide reasonable functional forms. Polynomial response functions estimated for water and nutrients imply substitutability among inputs everywhere on the function.

Researchers using the agronomic approach recently estimated von Liebig response functions for nutrients and water (Ackello-Ogutu, Paris, and Williams, 1985; Grimm, Paris, and Williams, 1987; Paris and Knapp, 1989). When an input is limiting, a von Liebig function behaves like a Leontief production function (with no substitutability among inputs). These authors discovered that, based on model specification tests,

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[1]Elaborate versions of the agronomically oriented research apply time-dated process models of plant growth to establish the effect of early and midseason growth and water stress on final yield (for example, Minhas, Parikh, and Srinivasan, 1974).

the von Liebig functions outperform polynomial functions.

The second category of research, beginning with the seminal work of Ruttan (1965), concentrates on labor, farm machinery, and other inputs as substitutes for land and water (Brown and Beattie, 1975; Madariaga and McConnell, 1984). This research applies its analysis of the productivity of irrigated agriculture as a tool of rational regional and national planning for agricultural supply and resource use.

The third category applies contemporary multioutput production methods to estimate production relationships for irrigated agriculture. Research results include estimates of Cobb-Douglas and translog production functions for bell peppers, eggplant, melons, onions, and tomatoes with three inputs (Just, Zilberman, and Hochman, 1983; Chambers and Just, 1989) and estimates of conditional factor demand functions for irrigation water and three irrigation technologies (Nieswiadomy, 1988).

Data availability has repeatedly limited these three avenues of research. Although agronomically sound, response functions estimated from field-experiment data cannot capture the substitution opportunities inherent in a full specification of farm inputs. For instance, most response functions do not quantify tradeoffs between irrigation water and irrigation technology or between irrigation water and land. The second research approach, in contrast, relies on farm-level data (rather than crop-specific data) that inevitably is aggregated to a county-level application using, for example, Census of Agriculture data. The second approach solves the problem of aggregating farm output over different commodities by measuring output in dollar value. However, aggregation obscures crop-specific relationships between output and inputs. The third research approach generally relies on time-series data to create adequate price variation for application of duality theory. These data requirements have restricted the number of crops studied and the geographic coverage.

Production Function Specification

Characteristics of the data determined many of the fundamental modeling decisions in this study. The primary data set is composed of cross-sectional microdata from the 1984 FRIS. The core variables are crop-specific observations of output per acre, irrigation water applied per acre, land, and irrigation technology. The core-variable data are the best available in terms of sample size and geographic and crop coverage.

The comparative strengths of the data motivate three modeling decisions. First, farm-level observations on crop-specific input and output quantities, rather than financial data, dictate a primal rather than a dual approach. Unlike the dual approach, the production-function approach requires no behavioral assumptions. That is, a production function is a purely physical relationship between inputs and output. It is not an economic optimization problem requiring either a maximization assumption on producer behavior or the separation of inputs into fixed and variable inputs. Second, without loss of generality, per-acre production functions are estimated rather than converting yield and water applied per acre to total output and water use to estimate conventional production functions (functions using total output as the dependent variable).[2] The per-acre and conventional production functions contain identical information in principle, but by using the per-acre data reported on the survey, we avoid introducing heteroskedastic error terms. Third, von Liebig response functions are not estimated because the FRIS data do not meet their requirements for detailed field-level data on agronomic factors of plant growth. Further, Berck and Helfand (1990) showed that, "even though an individual plant may actually grow via a von Liebig production function, in the aggregate a smooth concave function may provide a better approximation for actual crop yields" (p. 990). This article's approach is consistent with their findings.

For each crop, the per-acre production function for the Cobb-Douglas specification is:[3]

$$y = A\, x_1^{\alpha}\, x_2^{\beta}\, x_3^{\gamma}\, x_4^{\delta} e^{\sum_{i=1}^{n}\rho_i z_i + \epsilon_1}, \tag{1}$$

[2]The relationship between conventional production functions and per-acre production functions (namely, that per-acre functions are algebraically derived from conventional production functions) rarely is recognized explicitly. Too frequently, researchers simply specify the output and input data on a per-acre basis and ignore land as an input, thereby imposing a constant returns-to-scale production function. Per-acre yield response functions generally assume that crop yields can be replicated on each acre, in effect assuming a production function that is multiplicatively separable in land.

[3]Assuming input nonjointness in crop production, the per-acre, crop-specific Cobb-Douglas production function follows directly from a conventional production function, such as

$$q = Bw^{\alpha} r^{\beta} c^{\gamma} n^{\phi},$$

where q is output of the crop, B is a constant, w is water, r is rainfall, c is cooling degree days, and n is land. As usual, returns to scale depend on summing the exponents, $\alpha+\beta+\gamma+\o$. To convert to a per-acre production function, divide both sides of the equation by n. This simplifies to (see next page)

where y is output per acre; x_1 is irrigation water applied per acre (acre-inches); x_2 is rainfall per acre (inches); x_3 is cooling degree days (days); x_4 is land (acres); e is the exponential function; z_i (i=1, ...,n) are a series of qualitative variables representing irrigation technology, water management, farm structure, climate, and soil quality; ϵ_1 is an error term that captures the cumulative effect of all excluded variables; and A, α, β, γ, δ, and the ρ_i (i=1,...,n) are parameters to be estimated. Because the functions are on a per-acre basis, the exponent on land measures returns to scale, rather than (as is conventional) the output elasticity of land. The output elasticity of land can be computed from estimates of the Cobb-Douglas exponents in equation 1. Estimates of crop-specific returns to scale and the output elasticities of water and land provide new information on production functions for irrigated crops.

The specification of the quadratic production function, following the approach of Caswell and Zilberman (1986, p. 800-2), is:

$$y = a + \sum_{i=1}^{3} b_i x_i + \sum_{i=1}^{3} c_i x_i^2 + \sum_{i=1}^{n} d_i z_i + \epsilon_2, \qquad (2)$$

where a, b_i (i=1,2,3), c_i (i=1,2,3), and d_i (i=1,...,n) are parameters to be estimated; ϵ_2 is an error term; and the remaining variables are defined as before. Cross-product interaction variables are not included in the quadratic specification for reasons discussed in footnote 8. Land is not an argument in the function because the quadratic specification imposes constant returns to scale.

Data and Variables

The primary data set is composed of 8,009 FRIS observations from the 17 Western States.[4] The FRIS survey instrument emphasizes irrigation-related decisions and contains no information on other purchased inputs and human capital. Crop-specific data are available for 13 crops: alfalfa hay, barley, corn silage, cotton, dry beans, grain corn, grain sorghum, other hay (other than alfalfa), potatoes, rice, soybeans, sugar beets, and wheat. For each crop, the survey reports output per acre, irrigation water applied per acre, harvested acreage, and irrigation technology (table 1).[5] Two dummy variables describe the irrigation technology used for water application. The impact on yield of sprinkler technology and subirrigation technologies are measured relative to gravity systems, the omitted irrigation technology. The appendix defines these and subsequent variables in more detail.

The FRIS survey includes several questions that permit construction of variables measuring the effects of farm-level water management decisions. Data from a question on irrigation scheduling ("the method of deciding when to apply water") were divided into two dummy variables (see the appendix). More sophisticated methods of irrigation scheduling should increase crop yields, other things equal. The FRIS also identifies the source of irrigation water on the farm. One hypothesis is that, because ground water typically provides more flexibility in timing of use than surface water, relying solely on surface water reduces yield. A confounding factor, though, is that surface and ground-water quality may differ, with ground water more saline than surface water in some regions (for instance, the San Joaquin Valley of California). However, data are not available to control for water quality. Finally, information on whether irrigation was discontinued because of unanticipated events forms the final irrigation-related dummy variable. Unanticipated discontinuation of irrigation for any reason should depress yields.

A set of variables not associated directly with onfarm irrigation practices is included to control for physical and structural characteristics of the farm. These 21 variables include four categories of information: farm structure variables; weather variables; climate variables; and soil quality variables. The appendix defines the variables and also describes a prior expectation for each variable's

$$\frac{q}{n} = B\left(\frac{w}{n}\right)^{\alpha}\left(\frac{r}{n}\right)^{\beta}\left(\frac{c}{n}\right)^{\gamma} n^{(\alpha+\beta+\gamma+\phi-1)},$$

or, converting to the notation used in the text,

$$y = Ax_1^{\alpha} x_2^{\beta} x_3^{\gamma} x_4^{\delta},$$

where $\delta = (\alpha+\beta+\gamma+\phi-1)$. The econometric analysis estimates the returns to scale, δ, directly. Production exhibits constant, decreasing, or increasing returns as δ is equal to, less than, or greater than zero. The output elasticity of land, ϕ, can be calculated from the estimates in equation 1 as $\phi = \delta+1-\alpha-\beta-\gamma$.

[4]The 17 Western States are Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming.

[5]Water prices must be high enough for producers to have the incentive to apply water at a rate other than the yield-maximizing water application rate. That is, the data should not be used to estimate a function if water prices are negligible and every producer is at the yield-maximizing point of a response function. Such an estimated function would simply trace out the envelope of a series of yield-maximizing points. Two published papers that utilize data from the 1984 FRIS (Negri and Brooks, 1990; Ogg and Gollehon, 1989) provide evidence that sufficiently high water prices and sufficient water-price variation exist to induce the observed variation in water application rates. In both papers, a water-price variable was highly significant in explaining irrigation technology choice and irrigation water demand, respectively.

Table 1—Characteristics of crop-specific variables[1]

Crop	Units	Irrigated crop yield		Irrigation water-application-rate[2]		Irrigated acres		Percentage of observations by irrigation technology[3]	
								Gravity	Sprinkler
		Mean	*std. dev.*	*Mean*	*std. dev.*	*Mean*	*std. dev.*	*Percent*	
Alfalfa	tons	4.33	2.05	29.1	19.5	263	560	59.7	39.6
Barley	bu.	79.5	26.5	20.7	14.5	253	515	51.3	47.7
Corn silage	tons	20.40	5.69	24.0	14.3	158	291	70.0	29.7
Cotton	lbs.	916	371	32.5	20.5	936	2,727	86.5	12.8
Dry beans	cwt.	20.43	6.03	22.6	13.6	200	286	57.9	41.9
Grain corn	bu.	132.1	31.9	22.1	13.3	606	1,085	53.9	45.6
Grain sorghum	bu.	86.0	27.3	16.9	10.0	328	397	71.9	27.6
Other hay	tons	2.14	1.21	22.9	16.7	594	1,381	78.5	19.4
Potatoes	cwt.	348	121	28.2	16.1	447	707	18.3	80.4
Rice	cwt.	67.8	13.0	62.5	21.2	856	1,033	100.0	0.0
Soybeans	bu.	37.9	10.9	12.1	8.1	196	226	50.5	49.5
Sugar beets	tons	23.4	5.7	32.9	16.6	319	386	74.7	25.3
Wheat	bu.	73.6	26.9	19.1	13.2	441	921	53.4	46.6

[1]Space limitations do not permit listing of the statistical characteristics or percentages of remaining variables used in the analysis. They are available from the authors.
[2]Irrigation water application rate measured as acre-inches per acre.
[3]The percentage of observations in other irrigation technologies is the difference between 100 percent and the percentages in gravity and sprinkler technologies.

sign. This extensive effort to account for as many production factors as possible was critical given the broad geographic coverage of the research.

Econometric Results

The alternative forms of per-acre production functions in equations 1 and 2 are estimated using ordinary least squares, with the Cobb-Douglas functions estimated in a linear-in-logarithms form. The number of estimated parameters changes by crop because the definitions of weather, climate, and soil-quality variables remain identical across crops. Thus, crops produced in diverse physical conditions have many parameters estimated. The most parameter estimates, 31, are with the quadratic forms for the alfalfa hay and other hay equations. In contrast, crops produced in more homogeneous conditions have fewer parameters estimated. The fewest estimates, 17, are with the Cobb-Douglas rice equation.

Assessing the Cobb-Douglas specification, significant parameters (at the 0.05 level) range from 19 of 27 estimated parameters for wheat and 18 of 26 for grain corn to 3 of 17 for rice and 4 of 22 for soybeans (table 2). The number of observations for each crop, which varies from 142 for rice to 3,516 for alfalfa, explains in part the range in performance across crops. Results for crops with many insignificant coefficients, like soybeans, do provide statistically significant information on the relationship between irrigation water and yield. The results are comparable for the quadratic specification, although table 3 reports results only for a selected set of independent variables.

The adjusted R^2's in the Cobb-Douglas case range from 0.603 for cotton and 0.539 for rice to 0.096 for soybeans and 0.094 for dry beans.[6] Rice is an interesting case of a relatively high adjusted R^2 associated with only a few statistically significant variables. This indicates multicollinearity, and multicollinearity diagnostics confirmed this.[7] With the quadratic form, adjusted R^2's are generally similar to the Cobb-Douglas case (table 3).

Since evaluating and selecting functional specification based on R^2's is inappropriate (Davidson and MacKinnon, 1981), we conduct non-nested specification tests. A subsequent section reports the test results.

[6]Adjusted R^2's reported in previous research for regression results using experimental data are higher than the adjusted R^2's reported here using survey data; see, for example, Grimm and others, or Yaron. The higher R^2's using experimental data are not surprising for two reasons. First, survey data are inherently noisy. Second, field experiments control for inputs other than water and nitrogen and the FRIS does not contain data on several inputs.

[7]With every regression equation, variance inflation factors (a multicollinearity diagnostic) were computed for each variable to indicate whether sufficient multicollinearity was present to potentially affect t-statistics. In general, multicollinearity is not a problem in this data set. Variance inflation factors are less than 10 except for the cases discussed explicitly in the text. The single systematic exception to the general rule is the weather variables. Footnote 10 describes multicollinearity in this context more fully.

Table 2—Crop-water production function estimates, Cobb-Douglas specification

Independent variable	Irrigated crop				
	Alfalfa	Barley	Corn silage	Cotton	Dry beans
	Tons	*Bu.*	*Tons*	*Pounds*	*Cwt.*
Crop-specific:					
Log IRRWATER	0.1382	0.0201	0.0856	0.1263	0.0257
(ac-in/ac)	(9.66)[1]	(1.13)	(4.20)	(5.23)	(0.92)
Log LAND[2]	0.0338	0.0146	0.0298	0.0123	–0.0032
(acres)	(4.73)	(1.49)	(2.84)	(1.38)	(–0.22)
SPKLRTECH	0.0713	0.0110	–0.0332	–0.1266	–0.0674
(d.v.)[3]	(3.33)	(0.40)	(–1.06)	(–3.36)	(–1.92)
SUBTECH	–0.0062	NA[4]	NA	NA	NA
(d.v.)	(–0.06)				
Farm-level:					
HIGHMGMT	0.1531	0.1113	0.0851	0.0342	0.0377
(d.v.)	(5.54)	(3.75)	(2.94)	(1.24)	(1.08)
LOWMGMT	–0.1603	–0.1020	NA	NA	NA
(d.v.)	(–4.28)	(–1.72)			
SURFACE	0.0034	–0.0154	–0.0492	–0.0168	–0.0011
(d.v.)	(0.15)	(–0.56)	(–1.78)	(–0.62)	(–0.03)
DSCNTN	–0.1298	–0.0914	–0.0530	–0.0291	–0.0703
(d.v.)	(–5.72)	(–3.10)	(–1.82)	(–1.00)	(–1.70)
LRGDRYLND	0.0039	–0.0975	–0.0276	–0.0679	0.0218
(d.v.)	(0.14)	(–2.75)	(–0.70)	(–1.77)	(0.45)
NONFAMILY	–0.0184	0.0411	0.0030	0.0520	0.0581
(d.v.)	(–0.76)	(1.44)	(0.11)	(1.95)	(1.57)
Weather:					
Log RAIN	–0.1119	–0.0398	0.0241	–0.0270	0.0603
(ac-in/ac)	(–5.40)	(–1.36)	(1.02)	(–1.24)	(1.61)
Log CDD	0.0178	–0.0262	0.0401	0.7598	0.1647
(days/ac)	(0.91)	(–1.15)	(0.92)	(7.26)	(3.24)
HRDRAIN	0.0435	–0.0573	–0.0469	–0.0189	–0.0744
(days)	(4.15)	(–2.91)	(–4.57)	(–1.02)	(–2.58)
HEAT90	0.0005	0.0002	–0.0007	–0.0080	–0.0025
(days)	(0.55)	(0.17)	(–0.59)	(–3.49)	(–1.26)
Climate:					
VERYDRY	–0.0150	0.0213	–0.0026	0.2669	0.1108
(d.v.)	(–0.47)	(0.46)	(–0.06)	(4.81)	(1.94)
DRY	0.0048	–0.0370	–0.0100	0.1285	0.1106
(d.v.)	(0.16)	(–0.86)	(–0.27)	(2.12)	(2.02)
WET	–0.1082	0.0678	0.0516	0.0074	NA
(d.v.)	(–1.84)	(0.75)	(0.84)	(0.13)	
VERYWET	0.0592	NA	0.2423	NA	NA
(d.v.)	(0.75)		(3.40)		
COLD	–0.0645	–0.0712	0.0113	NA	NA
(d.v.)	(–1.33)	(–1.22)	(0.12)		
COOL	–0.0322	–0.0047	–0.0805	NA	–0.0354
(d.v.)	(–0.99)	(–0.11)	(–2.06)		(–0.62)
WARM	0.1398	–0.2563	–0.1042	0.0327	–0.1508
(d.v.)	(3.31)	(–3.96)	(–2.34)	(0.43)	(–2.08)
HOT	0.1780	–0.0770	–0.0651	0.0010	–0.0102
(d.v.)	(4.06)	(–1.13)	(–1.06)	(0.01)	(–0.13)
Soil quality:					
LNDCLASSA	0.0633	0.1157	0.0263	0.0864	–0.0789
(d.v.)	(1.78)	(1.85)	(0.64)	(2.92)	(–1.22)
LNDCLASSC	–0.1354	–0.0595	–0.0309	–0.2316	0.0517
(d.v.)	(–5.78)	(–1.20)	(–0.89)	(–3.12)	(0.93)
SANDY	–0.0429	–0.0788	–0.0366	–0.0349	0.2277
(d.v.)	(–1.25)	(–1.36)	(–0.82)	(0.73)	(3.68)
CLAYEY	0.0032	–0.0448	–0.1034	0.0450	0.0032
(d.v.)	(0.08)	(–0.94)	(–2.28)	(1.20)	(0.05)
SLOPE	0.0202	0.0127	0.0142	0.0325	0.0040
(% slope)	(3.76)	(1.90)	(1.71)	(1.74)	(0.36)
Intercept	0.7819	4.4707	2.3971	0.9157	1.7854
	(5.42)	(24.19)	(8.02)	(1.43)	(5.37)
Adjusted R^2	0.193	0.104	0.110	0.603	0.094
No. observations	3,516	1,169	734	411	748

(continued)

Table 2—Crop-water production function estimates, Cobb-Douglas specification (continued)

Independent variable	Irrigated crop			
	Grain corn	Grain sorghum	Other hay	Potatoes
	Bu.	*Bu.*	*Tons*	*Cwt.*
Crop-specific:				
Log IRRWATER	0.0641	0.1147	0.0779	0.1145
(ac-in/ac)	(4.72)	(4.50)	(4.49)	(3.92)
Log $LAND^2$	0.0478	0.0360	–0.0332	0.0301
(acres)	(9.01)	(2.97)	(–3.72)	(2.63)
SPKLRTECH	–0.0357	–0.0492	0.1599	0.0305
(d.v.)	(–2.20)	(–1.35)	(4.07)	(0.69)
SUBTECH	NA	NA	–0.0835	NA
(d.v.)			(–0.91)	
Farm-level:				
HIGHMGMT	0.0545	0.0341	0.1283	0.0645
(d.v.)	(3.82)	(1.02)	(2.49)	(1.94)
LOWMGMT	–0.0602	NA	–0.1009	NA
(d.v.)	(–1.28)		(–2.33)	
SURFACE	–0.0472	–0.0896	–0.0137	0.0223
(d.v.)	(–2.73)	(–1.77)	(–0.38)	(0.62)
DSCNTN	–0.0671	–0.1149	–0.0666	–0.0583
(d.v.)	(–3.94)	(–3.57)	(–2.03)	(–1.25)
LRGDRYLND	–0.0450	0.0339	0.0557	–0.0397
(d.v.)	(–2.43)	(1.01)	(1.18)	(–0.81)
NONFAMILY	0.0295	–0.0052	–0.0502	–0.0263
(d.v.)	(1.87)	(–0.14)	(–1.49)	(–0.79)
Weather:				
Log RAIN	0.0328	0.0901	–0.1191	–0.2311
(ac-in/ac)	(2.15)	(2.49)	(–3.34)	(–5.24)
Log CDD	0.1379	0.0943	0.0439	–0.0463
(days/ac)	(4.20)	(0.87)	(2.30)	(–1.52)
HRDRAIN	–0.0118	0.0031	–0.0048	0.0317
(days)	(–2.40)	(0.26)	(–0.27)	(0.98)
HEAT90	–0.0019	–0.0015	–0.0007	–0.0015
(days)	(–2.59)	(–0.76)	(–0.46)	(0.81)
Climate:				
VERYDRY	0.0105	–0.1047	0.0173	0.0466
(d.v.)	(0.41)	(–1.62)	(0.40)	(0.64)
DRY	0.0513	–0.1182	0.0784	0.1130
(d.v.)	(2.78)	(–2.84)	(1.89)	(1.65)
WET	–0.0408	–0.0081	0.0419	NA
(d.v.)	(–1.64)	(–0.14)	(0.49)	
VERYWET	–0.0451	–0.0056	–0.0323	NA
(d.v.)	(–1.17)	(–0.06)	(–0.45)	
COLD	NA	NA	0.0667	–0.1037
(d.v.)			(0.92)	(–1.22)
COOL	–0.0687	0.0622	0.0668	0.0812
(d.v.)	(–3.15)	(0.52)	(1.12)	(1.37)
WARM	0.0318	–0.0913	0.2920	–0.1448
(d.v.)	(1.41)	(–2.08)	(3.54)	(–1.27)
HOT	–0.1974	–0.2430	0.2225	NA
(d.v.)	(–5.36)	(–3.21)	(2.71)	
Soil quality:				
LNDCLASSA	0.0178	0.0183	0.1436	–0.0638
(d.v.)	(0.83)	(0.42)	(1.63)	(–0.53)
LNDCLASSC	–0.0489	–0.2820	–0.1216	–0.0573
(d.v.)	(–2.29)	(–4.24)	(–3.67)	(–1.41)
SANDY	0.0227	–0.0649	–0.0307	–0.0511
(d.v.)	(1.10)	(–1.27)	(–0.60)	(–0.88)
CLAYEY	–0.0551	–0.0147	0.0126	NA
(d.v.)	(–2.52)	(–0.35)	(0.19)	
SLOPE	0.0157	–0.0293	0.0232	0.0256
(% slope)	(3.23)	(–1.10)	(3.41)	(3.00)
Intercept	3.5033	3.3371	0.4746	5.7665
	(15.83)	(4.56)	(2.67)	(22.86)
Adjusted R^2	0.226	0.194	0.172	0.312
No. observations	1,485	623	1,492	393

(continued)

Table 2—Crop-water production function estimates, Cobb-Douglas specification (continued)

Independent variable	Irrigated crop			
	Rice	Soybeans	Sugar beets	Wheat
	Cwt.	*Bu.*	*Tons*	*Bu.*
Crop-specific:				
Log IRRWATER	0.0868	0.0938	0.0549	0.0833
(ac-in/ac)	(2.25)	(2.48)	(1.96)	(6.66)
Log LAND[2]	–0.0107	–0.0151	–0.0246	0.0257
(acres)	(–0.85)	(–0.86)	(–1.91)	(4.13)
SPKLRTECH	NA	–0.0337	0.0091	–0.0289
(d.v.)		(–0.79)	(0.26)	(–1.53)
SUBTECH	NA	NA	NA	NA
(d.v.)				
Farm-level:				
HIGHMGMT	0.0241	0.1231	0.0163	0.0694
(d.v.)	(0.63)	(3.24)	(0.54)	(3.97)
LOWMGMT	NA	NA	NA	–0.1268
(d.v.)				(–1.99)
SURFACE	–0.0226	–0.2068	–0.0779	0.0465
(d.v.)	(–0.88)	(–2.80)	(–2.62)	(2.45)
DSCNTN	NA	–0.0260	–0.0899	–0.0913
(d.v.)		(–0.52)	(–2.13)	(–4.71)
LRGDRYLND	–0.0481	0.0172	–0.1295	–0.0751
(d.v.)	(–1.38)	(0.32)	(–3.22)	(–3.37)
NONFAMILY	0.0026	0.0594	0.0222	0.0374
(d.v.)	(0.09)	(1.28)	(0.75)	(2.08)
Weather:				
Log RAIN	0.1216	0.2070	–0.0594	–0.0659
(ac-in/ac)	(1.60)	(1.82)	(–2.24)	(–3.97)
Log CDD	–0.2268	0.3706	0.2116	–0.0603
(days/ac)	(–0.84)	(1.78)	(2.33)	(–2.83)
HRDRAIN	–0.1394	–0.0329	–0.1085	–0.0264
(days)	(–5.25)	(–2.17)	(–3.79)	(–3.27)
HEAT90	0.0042	–0.0017	–0.0030	0.0014
(days)	(0.81)	(–0.52)	(–1.52)	(1.70)
Climate:				
VERYDRY	NA	NA	0.0878	0.1887
(d.v.)			(1.80)	(6.66)
DRY	0.0186	–0.0701	0.1153	–0.0049
(d.v.)	(0.28)	(–0.10)	(2.57)	(–0.20)
WET	–0.0853	–0.0095	NA	–0.1584
(d.v.)	(–1.01)	(–0.16)		(–3.28)
VERYWET	NA	–0.0727	NA	–0.1830
(d.v.)		(–0.92)		(–2.43)
COLD	NA	NA	NA	–0.0715
(d.v.)				(–1.60)
COOL	NA	0.0681	–0.1184	–0.0188
(d.v.)		(0.60)	(–2.14)	(–0.68)
WARM	NA	–0.0820	–0.1000	–0.0958
(d.v.)		(–1.23)	(–1.81)	(–3.53)
HOT	–0.0097	NA	–0.1282	–0.0996
(d.v.)	(–0.09)		(–1.71)	(–2.74)
Soil quality:				
LNDCLASSA	0.0080	0.0413	0.0436	–0.0104
(d.v.)	(0.15)	(0.83)	(0.64)	(–0.34)
LNDCLASSC	NA	NA	–0.0885	–0.1210
(d.v.)			(–1.88)	(–4.81)
SANDY	NA	0.0084	NA	–0.0070
(d.v.)		(0.14)		(–0.24)
CLAYEY	0.0057	–0.0111	–0.0285	0.0268
(d.v.)	(0.14)	(–0.17)	(–0.72)	(1.05)
SLOPE	–0.0038	–0.0034	0.0191	0.0254
(% slope)	(–0.13)	(–0.16)	(1.70)	(5.44)
Intercept	5.2658	0.4506	1.9147	4.2803
	(2.86)	(0.35)	(3.26)	(28.57)

(continued)

Table 2—Crop-water production function estimates, Cobb-Douglas specification (continued)

Independent variable	Irrigated crop			
	Grain corn	Grain sorghum	Other hay	Potatoes
	Bu.	*Bu.*	*Tons*	*Cwt.*
Adjusted R^2	0.539	0.096	0.369	0.373
No. observations	142	333	288	1,923

[1]Numbers in parentheses are t-statistics.
[2]As described in the text, coefficients on the land variable measure returns to scale because the production functions are on a per-acre basis.
[3]d.v. = dummy variable.
[4]NA = insufficient observations available to estimate the variable.

Table 3—Crop-water production function estimates, selected variables in quadratic specification

Crop	IRRWATER (ac-in/ac)	IRRWATER SQUARED (ac-in/ac sq)	SPKLRTECH (d.v)[1]	HIGHMGMT (d.v.)	LOWMGMT (d.v.)	SURFACE (d.v.)	DSCNTN (d.v.)	Adjusted R^2
Alfalfa	0.0268	−0.000094	0.2707	0.4687	−0.3586	−0.0896	−0.3483	0.342
(tons)	(6.12)[2]	(−2.02)	(4.06)	(5.36)	(−3.04)	(−1.29)	(−4.91)	
Barley	0.0941	−0.0009	0.6658	9.6629	−5.0046	−2.1349	−7.1485	0.141
(bu.)	(0.74)	(−0.59)	(0.38)	(5.10)	(−1.33)	(−1.22)	(−3.80)	
Corn silage	0.2016	−0.0021	−0.1522	1.3428	NA[3]	−0.6422	−1.0608	0.116
(lbs.)	(3.97)	(−2.88)	(−0.28)	(2.58)		(−1.30)	(−2.06)	
Cotton	5.6867	−0.0358	−84.7650	24.1197	NA	−14.1238	−19.1478	0.626
(lbs.)	(3.10)	(−2.08)	(−2.92)	(1.10)		(−0.65)	(−0.83)	
Dry beans	0.1253	−0.0016	−1.2499	0.4497	NA	0.3610	−1.0272	0.080
(cwt.)	(2.08)	(−2.11)	(−1.81)	(0.65)		(0.52)	(−1.25)	
Grain corn	0.8884	−0.0097	−0.4071	7.3661	−7.6723	−5.6206	−7.5591	0.220
(bu.)	(4.92)	(−4.08)	(−0.22)	(4.42)	(−1.40)	(−2.77)	(−3.81)	
Grain sorghum	1.1294	−0.0158	−3.2451	4.1714	NA	−7.5860	−8.5330	0.204
(bu.)	(3.78)	(−2.70)	(−1.26)	(1.76)		(−2.06)	(−3.73)	
Other hay	0.0086	−0.000013	0.4161	0.2330	−0.0889	0.0015	−0.1478	0.205
(tons)	(1.96)	(−0.26)	(4.91)	(2.09)	(−0.95)	(0.02)	(−2.09)	
Potato	2.9106	−0.0220	10.9760	26.0361	NA	15.7978	−23.2053	0.369
(cwt.)	(3.31)	(−2.52)	(0.76)	(2.43)		(1.36)	(−1.56)	
Rice	−0.0606	0.0014	NA	2.1920	NA	−0.4599	NA	0.412
(cwt.)	(−0.32)	(0.98)		(0.81)		(−0.24)		
Soybeans	0.4013	−0.0052	−0.1076	3.1563	NA	−4.1481	−0.9587	0.133
(bu.)	(2.14)	(−1.56)	(−0.08)	(2.62)		(−1.76)	(−0.62)	
Sugar beets	0.1161	−0.0010	−0.0142	−0.0012	NA	−1.1596	−2.1096	0.379
(tons)	(1.80)	(−1.36)	(−0.02)	(−0.002)		(−1.73)	(−2.29)	
Wheat	0.5035	−0.0048	−1.2573	5.0418	−6.4452	2.9350	−5.6806	0.422
(bu.)	(5.48)	(−3.93)	(−1.06)	(4.61)	(−1.61)	(2.43)	(−4.65)	

[1]d.v. = dummy variable.
[2]Numbers in parentheses are t-statistics.
[3]NA = insufficient observations available to estimate the variable.

Irrigation Water

Irrigation water is a highly significant determinant of crop output regardless of the functional form, with most t-statistics exceeding significance at the 0.01 level (tables 2 and 3). Only a few coefficients are insignificant: barley, in both specifications, despite substantial variation in water application rates (table 1); dry beans in the Cobb-Douglas specification; and rice and sugar beets in the quadratic specification. With rice and sugar beets, the insignificance is due to multicollinearity between the linear and squared terms for irrigation water. A joint test of the significance of both coefficients shows significance at the 0.05 and 0.10 levels in the rice and sugar beets equations, respectively.

The parameter estimates also indicate the diminishing marginal productivity of irrigation water for all 13 crops. Although the quadratic function does not impose concavity, the function is concave in

water for every crop but rice.[8] The Cobb-Douglas function imposes concavity, with significant coefficients on the water variable providing statistical confirmation of diminishing marginal productivity.

The Cobb-Douglas results are only somewhat comparable to previous empirical estimates. The coefficient estimates on the irrigation water variable range from 0.020 (barley) to 0.138 (alfalfa). Previous estimates for five vegetables varied from 0.005 to 0.079 (Just and others) and for wheat from 0.041 to 0.241 depending on the model and the econometric technique (Antle and Hatchett, 1986). For the majority of crops, the Cobb-Douglas results provide new empirical estimates.

Comparing the quadratic functions to previous research reveals distinct differences in yield-maximizing water application rates. Yield-maximizing rates reported here are significantly higher than previous results for the five crops for which comparisons can be made (Grimm and others, p. 188).[9] The differences can be attributed to data sources. Previous research relies on data from field experiments (experimental test plots), producing two substantive implications for the comparisons. First, field experiments typically involve relatively uniform water applications, while water applications are nonuniform in actual production activity. Thus, maximum yield estimates based on actual behavior occur at higher water application rates than in field experiments. Second, field experiments are designed in part to characterize maximum yield. With survey data, yield-maximizing irrigation rates will tend to be outside the range of most of the observed data because rational profit-maximizing growers do not produce where the marginal product of water is zero or negative. This article's quadratic functions, while concave in irrigation water, generate near-linear functions for many of the crops. Thus, survey data may not accurately characterize maximum yield.

Land

With the Cobb-Douglas functions specified on a per-acre basis, estimates of the coefficient on land must be computed from the estimated parameters (see footnote 3). For all crops except cotton and soybeans, land coefficients range between 0.73 and 1.20. Table 4 reports the coefficients as output elasticities of land. The land coefficient estimates are roughly an order of magnitude greater than the estimates for irrigation water, indicating that land overshadows irrigation water as a production input.

Land coefficient estimates are not available from the quadratic functions because the land input cancels out when specifying the function on a per-acre basis.

Water Management Variables

Modern irrigation technologies either increase water application efficiency *per se* or substitute for poorer quality land, like sandy soil or relatively sloped topography (Caswell and Zilberman 1986; Lichtenberg, 1989). Both roles are expected to increase crop yields provided that other variables control for land quality. The dummy variable indicating the presence of sprinkler irrigation, SPKLRTECH, has the expected sign and significance with alfalfa hay and other hay, increasing yields by 0.27 ton and 0.42 ton, respectively, in the quadratic specification (table 3). With the Cobb-Douglas form, coefficients on SPKLRTECH have significant, negative signs with cotton, dry beans, and grain corn. SPKLRTECH frequently is insignificant with the remaining crops.

Evidence from previous research that irrigation technology augments low-quality land explains in part the weak results for irrigation technology. If sprinklers tend to be located in fields with relatively sandy soil or sloped topography, they serve incidentally as a field-level proxy for poor land quality. The field level is a finer degree of geographic detail than the county-level soil quality variables used in the estimation. Thus, the two functions of irrigation technology—reducing water application rates versus augmenting land quality—cannot be accurately isolated given the current land-quality variables.

The other irrigation-related variables generally have the anticipated signs. Relying on more

[8] Cross-product interaction variables are not included in the quadratic specification for two empirical reasons. First, interaction variables between irrigation water and irrigation technology and between irrigation water and water management introduced serious multicollinearity into the analysis. The consequence was inefficient estimates of irrigation water coefficients: without the interaction variables, 10 of 13 linear terms for the water variables are statistically significant; with the variables, this drops to 2 of 13 significant variables. Second, the weather, climate, and soil quality variables are included as general indicators of physical conditions. These variables are not used as determinants of water productivity (via cross-product interaction terms with irrigation water) because, as county-level data, they are not sufficiently accurate for that purpose. Any information added by this type of interaction variables would be suspect.

[9] Grimm and others computed yield-maximizing water levels for von Liebig and polynomial functions for five crops. Our results for the same five crops find that, with the exception of corn silage, our estimates of quadratic functions require more water to maximize yield than their polynomial functions. Comparing results in terms of acre-inches per acre (with the Grimm and others results presented first), the relations include: corn silage, 54.7 versus 47.5; cotton, 37.7 versus 79.5; grain corn, 24.9 versus 45.6; sugar beets, 50.2 versus 56.6; and wheat, 33.8 versus 52.4.

Table 4—Output elasticity measures of irrigation water and land

Crop	Output elasticity of irrigation water		Output elasticity of land	
	Cobb-Douglas	Quadratic[1]	Cobb-Douglas	Quadratic[1]
Alfalfa	0.138	0.145	0.990	0.901
Barley	0.020	0.014	1.061	1.164
Corn silage	0.086	0.118	0.880	1.022
Cotton	0.126	0.115	0.153	0.435
Dry beans	0.030	0.061	0.746	0.709
Grain corn	0.064	0.070	0.813	0.797
Grain sorghum	0.115	0.112	0.737	1.003
Other hay	0.078	0.112	0.964	1.428
Potatoes	0.114	0.128	1.193	0.885
Rice	0.087	0.107	1.008	1.464
Soybeans	0.094	0.088	0.313	0.767
Sugar beets	0.055	0.064	0.768	1.206
Wheat	0.083	0.082	1.069	1.011

[1]Elasticity measures for the quadratic functions are evaluated at mean input levels of the data.

sophisticated techniques of irrigation scheduling (HIGHMGMT) improves yields for 8 of 13 crops (alfalfa, barley, corn silage, grain corn, other hay, potatoes, soybeans, and wheat). Relying on fewer sophisticated techniques (LOWMGMT) depresses yields for three of five crops in the Cobb-Douglas form (alfalfa, other hay, and wheat), but only one of five crops in the quadratic form (alfalfa). The irrigation scheduling coefficients indicate that, with some crops, managerial inputs can successfully substitute for irrigation water. Discontinuing irrigation for a period of the growing season (DSCNTN) depresses yields for 7 of 12 crops. Finally, farms with surface water as their only source (SURFACE) experience lower yields of grain corn, grain sorghum, soybeans, and sugar beets in at least one specification, and a higher yield of wheat in both specifications. The tendency for lower yields with SURFACE is consistent with the hypothesis that complete reliance on surface water constrains irrigation flexibility. For most crops, though, relying solely on surface water does not constrain options enough to influence yield.

Weather and Other Variables

While rainfall was expected to increase yields, the results suggest otherwise. Coefficients on RAIN are positive and significant only with the Cobb-Douglas specification for grain corn and sorghum and the quadratic specification for dry beans.[10] RAIN coefficients are negative and significant with five crops, and otherwise are not significantly different from zero. One plausible explanation is that, while rainfall contributes water for plant growth, it can be both untimely and excessive. More detailed data on the timing and volume of irrigations, rainfall, and plant growth would be required to distinguish the different effects of rainfall.

Energy availability for plant growth, as measured by cooling degree days (CDD), contributed positively to yields of seven crops.[11] The common elements for most of these crops are either an agronomic requirement for a relatively long growing season (cotton, grain corn, and sugar beets) or an opportunity for multiple harvests (alfalfa hay and other hay) (Hagan, Haise, and Edminster, 1967; Jensen, 1969). CDD affected the yields of wheat and barley negatively for at least one functional form. The negative coefficients can be interpreted as excessive heat. Small grains, such as wheat and barley, can suffer heat stress both in the spring (early growth stages) and midsummer (late stages) (Ash and Lin, 1987).

The remaining variables include control variables for general farm characteristics, extreme weather events, climate, and soil quality. Variables in these four categories frequently are statistically significant determinants of crop output. The variables performing best include HRDRAIN, LNDCLASSC, SLOPE, and IRRSHARE (the own crop's share of total irrigated cropland). They are significant in explaining output of 7-8 of the 13 crops, and their signs conform to expectations. On the other hand, HEAT90 had little explanatory value.

[10]According to the multicollinearity diagnostics, the linear and squared terms for the weather variables in the quadratic regressions have a high degree of multicollinearity. Despite the multicollinearity, t-statistics are statistically significant at the 0.10 level or better for the weather variables with 9 of the 13 crops. A problem of multicollinearity resulting in insignificant parameter estimates on the weather variables appears to have occurred only with the quadratic regressions for corn silage, grain sorghum, rice, and sugar beets. Multicollinearity probably occurs with these crops because they are produced in relatively small geographic areas under relatively homogeneous weather conditions.

[11]The contribution of CDD to cotton output is notably large. With the Cobb-Douglas form, the elasticity of output with respect to CDD is 0.7598. This is substantially larger than the combined contribution of irrigation water and land to cotton production.

While a complete discussion of these results is omitted to conserve space, either the previous section or the appendix contains expectations for the variables' signs, and table 2 reports their coefficient estimates for the Cobb-Douglas function. Although not reported, results for these variables with the quadratic form are very consistent with the Cobb-Douglas form. An extended discussion of these variables and a complete set of results for the quadratic form are available from the authors.

General Production Characteristics

The econometric results also produce information on general characteristics of the production functions. This section focuses on returns to scale, output elasticities of irrigation water and land, and substitutability of irrigation water and land.

Returns to Scale

With the specification of per-acre production functions, the estimated coefficient on the land variable in the Cobb-Douglas form directly measures returns to scale in irrigated production (table 2). (The quadratic function imposes constant returns to scale.) A significant positive coefficient on the land variable indicates increasing returns to scale, a significant negative coefficient indicates decreasing returns to scale, and a coefficient not significantly different from zero indicates constant returns to scale. Adding 1.0 to the land coefficient produces the conventional measure of returns to scale; the resulting number indicates homogeneity of degree k, where $k = 1$ is linear homogeneity. The results range from $k = 1.048$ for grain corn to $k = 0.967$ for other hay crops. Alfalfa, corn silage, grain corn, grain sorghum, potatoes, and wheat exhibit increasing returns to scale technologies. Barley, cotton, dry beans, rice, soybeans, and sugar beets exhibit constant returns to scale. Only other hay crops exhibit decreasing returns to scale. While the results for wheat are consistent with Antle and Hatchett's, comparable information does not exist on crop-specific returns to scale for the other 12 irrigated crops. The results suggest that, while imposing constant returns to scale is not necessarily an accurate assumption, it may be defensible for many purposes because the deviations from constant returns to scale are minor.

Output Elasticities of Irrigation Water

The output elasticity of irrigation water provides a common measure across crops and functional forms of the effect of irrigation water on output (table 4). The estimated elasticities consistently are very inelastic across crops and functional forms. Across crops, the elasticities fall in a fairly narrow range of 0.014 (barley) to 0.145 (alfalfa). Across functional forms for the same crop, other hay crops show the largest disparity in estimated elasticities, with a difference of only 0.034. The small differences across functional forms lend credibility to the results.

The elasticities give insight into the production consequences of irrigation water conservation. The results provide persuasive evidence that, within the broad range of water application rates observed in the data (table 1), output is very inelastic with respect to water. In a period of competition for existing Western water supplies with no new supplies on the horizon, the elasticities imply that reductions in production associated with diminished irrigation water supply would be much smaller, proportionately, than the water supply reductions. For these 13 irrigated crops, for example, a 10-percent reduction in water use would induce at most a 1.5-percent reduction in output, *ceteris paribus*. Using mean water application rates (table 1), a 10-percent reduction in water equals 3.25 acre-inches per acre and 2.91 acre-inches per acre on cotton and alfalfa, respectively. This translates into an average per-acre decline of 10.5 pounds in cotton production and 0.063 tons in alfalfa production using the quadratic elasticities. Given the mean yields of 916 pounds per acre of cotton and 4.326 tons per acre of alfalfa, the output reductions are relatively minor.[12]

Output Elasticities of Land

Compared with irrigation water, output elasticities of land show relatively greater elasticity and a wider range of estimates (table 4).[13] The range across crops shows that land differs markedly in its contribution to crop output. Regardless of functional form, the barley, rice, and wheat elasticities are relatively elastic, while the soybean and cotton elasticities are quite inelastic. Elasticities for alfalfa, dry beans, grain corn, grain sorghum, and silage corn are slightly inelastic to

[12]These calculations can be used to predict the impact of a 10-percent reduction in irrigation water on average per-farm cotton output and alfalfa output. Based on the mean irrigated cotton acreage on a cotton-producing farm, 936 acres, and mean irrigated alfalfa acreage on an alfalfa-producing farm, 263 acres (table 1), a 10-percent reduction in irrigation water use translates into 254 acre-feet of conserved water and 9,828 pounds of forgone cotton output or, for alfalfa, 65 acre-feet of conserved water and 16.6 tons of forgone alfalfa output.

[13]Transforming the per-acre quadratic function to a standard quadratic production function, accomplished by multiplying through by land, permits computation of land's output elasticity for the quadratic form. The Cobb-Douglas elasticities are computed using the relationship in footnote 3 and information from table 2.

unitary elastic, falling in the range of 0.7 to 1.0 for both functional forms. Unlike the output elasticities of water, land's output elasticities are not sufficiently uniform to draw general policy-oriented conclusions.

Technical Substitution of Irrigation Water and Land

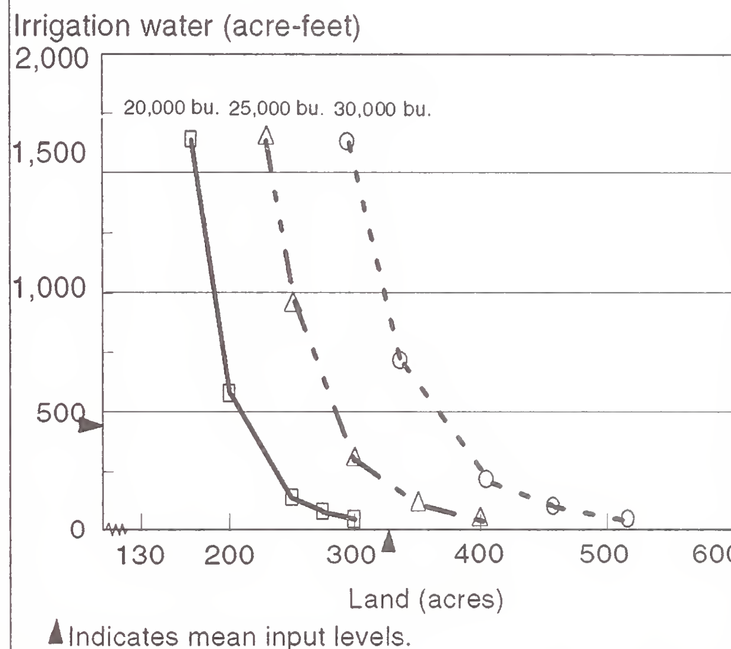
While the elasticities indicate that land is more important to production than irrigation water, the relative contribution of the two inputs can be analyzed most effectively by assessing their substitutability. Two procedures demonstrate substitutability, the marginal rate of technical substitution between water and land (MRTS) and water-land isoquants. Estimates of the Cobb-Douglas case are presented because of their computational simplicity.

The MRTS between irrigation water and land measures the volume of water required to substitute for an acre of land to hold output constant (that is, at a point on an isoquant). The Cobb-Douglas MRTS equals $(-ø/\alpha)$ (w/n), where w is water, n is land, α is water's exponent, and ø is land's exponent. Evaluated at the crops' mean water and land input levels, selected MRTS levels are: alfalfa –20, barley –85, cotton –4, grain corn –22, grain sorghum –9, potatoes –23, and wheat –20. Highly inelastic output elasticities on water or land explain the extreme cases of barley and cotton. Since barley's output elasticity of water is so inelastic (α equals 0.020), a large volume of water is required to substitute for land. Similarly, since cotton's output elasticity of land is so inelastic (ø equals 0.153), a relatively small volume of water is required to substitute for land.

Calculating the water application rate implied by the MRTS levels provides another perspective. For instance, sorghum's MRTS means that 9 acre-feet of water must be applied to compensate for a marginal decline in sorghum acreage. Since farms growing sorghum average 328 acres in the crop (table 1), applying 9 acre-feet over 328 acres minus the marginal decline in acreage results in a change in application rate of 0.33 acre-inch per acre. That is, increasing water use by 0.33 acre-inch per acre on the remaining sorghum acres keeps sorghum output constant. For other crops, the increases in water application rates (in acre-inches per acre) that hold output levels constant are: alfalfa 0.93, barley 4.02, cotton 0.05, grain corn 0.44, potatoes 0.61, and wheat 0.54.

Isoquants graphically represent a continuum of rates of input substitution. Figure 1 illustrates water-land isoquants for sorghum's Cobb-Douglas production function.[14] For example, 25,000 bushels of sorghum can be produced by applying either 168 acre-feet to 328 acres (a water application rate of 0.51 acre-feet per acre) or 460 acre-feet to 280 acres (a water application rate of 1.64 acre-feet per acre). Both water application rates are well within two standard deviations of sorghum's mean rate (see table 1).

Figure 1
Grain sorghum isoquants, Cobb-Douglas specification[1]



[1]Isoquants are drawn while holding all other inputs constant. Returns to scale consequently cannot be displayed via a ray through the origin (as in the classic textbook display).

The water-land isoquant and MRTS levels demonstrate a final critical point: water and land *do* substitute. For crops with Cobb-Douglas or quadratic production functions, irrigated production does not occur with Leontief, fixed-coefficient technologies in water and land inputs. As microeconomic principles suggest, the optimal water-land input combinations depend on relative prices of water and land (among other factors).

Specification Tests

To test if either the quadratic model or the Cobb-Douglas model is correctly specified, we apply the non-nested J-test (Davidson and MacKinnon, 1981). Unlike ordinal measures that select one model in preference to another (such as R^2), non-nested hypothesis tests attempt to establish the "validity" of one or more alternative specifications. The test is conducted in two stages. In the first

[14]Sorghum is presented because it is one of the crops for which the J-test results do not reject the Cobb-Douglas form. The J-test results are described in the next section.

stage, the J-test designates one model as the null hypothesis and the competing model as the alternative hypothesis. The test involves using the predicted values from the alternative model as an explanatory variable in the null-hypothesis model. If the coefficient on the predicted-value variable is statistically different from zero, the test rejects the null-hypothesis model as the "true" specification. In the second stage, the roles of the models are reversed and the test procedure repeated. Thus, the J-test may reject both specifications, accept both specifications, or accept one specification.

The J-test should not be construed as determining the statistical validity of particular coefficient estimates and their related output elasticity measures. As a specification test, J-test results do not affect the interpretation given above of the econometric results.

At the 0.05 level of significance, the J-test rejects both the Cobb-Douglas and quadratic specifications for seven crops: alfalfa, corn silage, grain corn, other hay, soybeans, sugar beets, and wheat (table 5). The test also: accepts the Cobb-Douglas specification for barley, grain sorghum, and rice; accepts the quadratic specification for cotton and dry beans; and accepts both specifications for potatoes. Rejecting both specifications for seven crops is not surprising given the complexity of "true" yield response functions.

In three cases, the J-test results can be compared with prior research. For grain corn and wheat, non-nested hypothesis tests by Grimm and others rejected quadratic specifications and accepted von Liebig functions (p. 190). By rejecting both the quadratic and the Cobb-Douglas forms for these two crops, our results are not inconsistent with their results. For sugar beets, they accepted the quadratic form while we reject it.

Table 5—J-test results

Crop	H_0: Cobb-Douglas H_1: Quadratic	H_0: Quadratic H_1: Cobb-Douglas	Conclusion[1]
Alfalfa	8.14[2]	6.56	Reject both
Barley	1.61	2.53	Accept Cobb-Douglas
Corn silage	2.24	3.48	Reject both
Cotton	4.71	–1.77	Accept quadratic
Dry beans	3.29	0.33	Accept quadratic
Grain corn	2.99	7.51	Reject both
Grain sorghum	1.21	2.82	Accept Cobb-Douglas
Other hay	4.82	2.71	Reject both
Potatoes	1.62	1.62	Accept both
Rice	1.30	3.85	Accept Cobb-Douglas
Soybeans	3.86	1.97	Reject both
Sugar beets	2.88	3.89	Reject both
Wheat	2.26	7.02	Reject both

[1] J-test results produced from applying a t-test at a 5-percent significance level.

[2] Entries are t-statistics from the coefficients on the additional variables used to create the J-test's artificial nesting model.

Three conclusions can be drawn from the specification tests. One, the J-test results demonstrate that selecting functional forms based on measures of fit can lead to erroneous conclusions. While measures of fit, such as adjusted R^2 or mean square error (MSE), always find a "better" specification, the J-test procedure chose a "true" specification on only 5 of the 13 crops evaluated here. Rice is the only crop for which the J-test, adjusted R^2, and MSE all select the Cobb-Douglas specification. While MSE or adjusted R^2 criteria prefer the quadratic specification on 10 of 13 crops, the J-test selects the quadratic as the "true" form on only cotton and dry beans. The J-test also fails to reject the hypothesis that the Cobb-Douglas specification correctly describes grain sorghum production even though the adjusted R^2 is larger with the quadratic function. Non-nested hypothesis testing thus provides an important decisionmaking tool when theoretical considerations do not dictate correct functional specifications.

Two, the J-test results underscore the difference between agronomic and economic criteria for choosing functional form. Based on agronomic principles, Hexem and Heady ruled out Cobb-Douglas functions *a priori* (p. 36). The Cobb-Douglas form contradicts agronomic principles because its total physical product in an input never achieves a maximum. In economic terms, however, the negative portion of a marginal physical product function—the portion beyond maximum yield—is irrelevant since profits cannot be maximized in that region. Because the FRIS data are based on actual production decisions rather than field experiments, the J-test demonstrates that the Cobb-Douglas function is well suited to economic evaluation of some crops. Functional forms that preclude negative marginal product should not be rejected *a priori* when the estimates evaluate the behavior of economic agents.

Three, other functional forms should be studied when data availablity does not restrict options. The J-test results indicate that the restrictions imposed by the Cobb-Douglas and quadratic functions frequently limit the analysis. With a set of detailed agronomic variables, the von Liebig specification should be evaluated. With more information on other purchased inputs (like labor, capital, and chemicals) or more variation in price data, more flexible functional forms such as the translog

function should be evaluated. This paper's results—based on application to 13 irrigated crops of the two most common forms of production functions—create a strong basis for future dialogue on the merits of various functional forms.

Summary and Conclusions

As the West moves fully into an era of water management and conservation, economic analysis of irrigated agriculture will continue to inform debate and decisions concerning Western water policy. Over 25 years ago, Ruttan's seminal research established a solid econometric foundation for assessing the profitability of regional irrigation development in the United States. His focus was on the extensive margin of irrigation development: what is the value of additional irrigated acreage in a region? In the emerging water-management era, assessment of regional water policy remains an important component of economic research. For example, U.S. Bureau of Reclamation policy, Federal law on interstate water marketing, and the possibility of climate change have implications for Western irrigated agriculture in its entirety. At the same time, the research focus has changed to the intensive margin: how will agricultural output be affected by input substitution and a reduction in irrigation water application rates?

This research establishes a partial foundation for evaluating irrigation water conservation and input substitution by estimating irrigated crop production functions using farm-level observations from the 1984 Farm and Ranch Irrigation Survey. The analysis is comprehensive, involving coverage of 13 irrigated crops with data from the 17 Western States. The analysis also is consistent, with uniformity across crops in functional specifications, data sources, and variable definitions. The combination of comprehensiveness and consistency creates the potential to use these results in further analysis of irrigated agriculture in the Western United States and, perhaps, other regions of the world.

For each of the 13 crops, the estimates capture the diminishing marginal productivity of irrigation water. Although certainly not surprising, this had not been established econometrically for many of the crops. The results also produce new information for these crops on the output elasticities of irrigation water, returns to scale, and the marginal rate of technical substitution between land and water.

J-test results fail to reject the Cobb-Douglas specification as the correct function for four crops and fail to reject the quadratic function for three crops. The acceptance of the Cobb-Douglas function for some crops implies that, when estimating a production function with survey data rather than field experiment data, functional forms without the ability to estimate maximum yield should not be excluded for consideration *a priori*. They are particularly suitable for evaluating behavior with economic content, which typically does not include applying water to the point of zero or negative marginal physical product.

The results of this research contain one immediate policy implication for water conservation in the West. Because the output elasticities of irrigation water are highly inelastic for every crop examined, producers should be able to mitigate many of the production impacts of water conservation efforts. This holds regardless of whether the conservation occurs from voluntary efforts, such as water marketing, or through policy-imposed restrictions in irrigation water supply.

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Appendix I—Variable Descriptions and Definitions

The 1984 Farm and Ranch Irrigation Survey (U.S. Department of Commerce, Bureau of the Census, 1986a) is a 6-percent stratified random sample of irrigated farms from the *1982 Census of Agriculture*. Weather, climate, and soil-quality variables also are emerged with the FRIS variables to capture the impact of the physical environment on crop yields. Hexem and Heady (chap. 10) pioneered the use of physical variables in estimating production functions for irrigated crops.

Crop-Specific Variables

YIELD	– Per-acre crop output.
IRRWATER	– Per-acre irrigation water application by crop.

LAND – Acres of the crop irrigated.

SPKLRTECH – Dummy variable that is 1 if the crop is irrigated with sprinkler technology and 0 if the technology is gravity or SUBTECH.

SUBTECH – Dummy variable that is 1 if the crop is irrigated with subirrigation technology and 0 if the technology is gravity or sprinkler.

All crop-specific variables are from 1984 FRIS.

Farm-Level Variables

HIGHMGMT – Dummy variable that is 1 if the irrigation decision considers any advanced irrigation management method (media reports, soil moisture sensing devices, or commercial scheduling) and 0 if the look of the crop, feel of the soil, or any LOWMGMT method was the basis for decision.

LOWMGMT – Dummy variable that is 1 if the irrigation decision is made on either a fixed time schedule method (calendar schedule) or the producer had no choice in when to irrigate (water delivered by irrigation organization in turn) and 0 if the look of the crop, feel of the soil, or any HIGHMGMT method was the basis for decision.

SURFACE – Dummy variable that is 1 if surface water is the sole water source and 0 if ground water is available.

DSCNTN – Dummy variable that is 1 if producers indicated that irrigation was discontinued long enough to affect yields and 0 otherwise.

LRGDRYLND – Dummy variable that is 1 if the farm has a relatively large nonirrigated acreage and 0 otherwise. Threshold levels for "relatively large" varied by crop but placed about 15 percent of the farms in the large class for each crop.

SMLIRRLND – Dummy variable that is 1 if the irrigated portion of the farm is relatively small and 0 otherwise. Threshold levels for "relatively small" varied by crop but placed about 15 percent of the farms in the small class for each crop.

IRRSHARE – The crop's share of total irrigated acres on the farm.

NONFAMILY – Dummy variable that is 1 if the farm is in estate or trust, prison farm, Indian reservation, or incorporated under State law and 0 if the farm is a family or partnership operation.

All farm-level variables except NONFAMILY are from the 1984 FRIS. NONFAMILY is from the *1982 Census of Agriculture* for the FRIS farms. The main text describes expectations for the performance of the variables directly associated with irrigation. Expected performances of the remaining farm-level variables are: farms with a large area in nonirrigated production (LRGDRYLND) have lower yields since managerial talent is diverted from irrigated crops and farm machinery conforms less to irrigated crop needs; farms with a small area in irrigated production (SMLIRRLND) have lower yields because these farms are more likely to be part-time operations; the crop's share of total irrigated acreage (IRRSHARE) can increase or decrease yields depending on whether it indicates that the crop is the focus of the operation or suggests that the farm is a monoculture operation receiving lower yields from failure to rotate crops; nonfamily ownership (NONFAMILY) increases yields if professional management improves crop output. IRRSHARE and SMLIRRLND are excluded from the Cobb-Douglas specification because they are highly collinear with the crop acreage variable, LAND.

Weather Variables

RAIN – The sum of April through September precipitation.

CDD – The sum of April through September base 65 cooling degree days. Daily cooling degree values represent the number of degrees Fahrenheit that the average temperature exceeds the base.

HRDRAIN – The number of days in the months April through June in which rainfall exceeded 1 inch.

HEAT90 – The number of days in June, July, and August that the maximum temperature exceeded 90 degrees.

All weather variables are from 1984 weather records for cooperative weather stations (U.S. Dept. Commerce, National Climatic Data Center, 1986c) that are selected to be representative of county conditions. RAIN measures the water available for plant growth in addition to irrigation water, while CDD measures solar energy availability. RAIN and CDD are continuous variables modeled as primary inputs (as in Madariaga and

McConnell) while HRDRAIN and HEAT90 are qualitative variables indicating extreme weather events. Among weather variables, we expect RAIN and CDD to affect yields positively and HRDRAIN and HEAT90 to affect yields negatively.

Climate Variables

VERYDRY – Dummy variable that is 1 if the average annual precipitation is less than 12 inches and 0 otherwise.

DRY – Dummy variable that is 1 if the average annual precipitation is 12 inches or greater but less than 18 inches and 0 otherwise.

WET – Dummy variable that is 1 if the average annual precipitation is 24 inches or greater but less than 30 inches and 0 otherwise.

VERYWET – Dummy variable that is 1 if the average annual precipitation is 30 inches or greater and 0 otherwise.

COLD – Dummy variable that is 1 if the average annual base 65 cooling degree days is less than 300 units and 0 otherwise.

COOL – Dummy variable that is 1 if the average annual base 65 CDD is 300 units or greater but less than 800 units and 0 otherwise.

WARM – Dummy variable that is 1 if the average annual base 65 CDD is 1,300 units or greater but less than 1,800 units and 0 otherwise.

HOT – Dummy variable that is 1 if the average annual base 65 CDD is 1,800 units or greater and 0 otherwise.

All climate variables are based on 1951-80 average climatic conditions for cooperative stations (U.S. Dept. Commerce, National Climatic Data Center, 1986b) that are selected to be representative of county conditions. The climate variables serve as proxies for unobserved producer decisions affected by climate but made prior to the observation of the production season's weather. For example, choice of seed type or crop rotation practices depend on climate, not weather. Given a certain seed variety, then, weather conditions during the growing season help to determine crop yield. Regional dummy variables are not included because climate variables likely capture most of the important regional differences in the study area.

The average precipitation and cooling degree day variables are specified as a series of dummy variables to minimize collinearity with the weather variables. Precipitation dummy variables measure the impact on yield relative to the omitted midrange condition of 18-24 inches. Similarly, as a surrogate for radiant energy available for plant growth, dummy variables for cooling degree days measure yield relative to the omitted midrange condition of 800-1,300 CDD. We expect positive coefficients on the rain variables (given the arid and semi-arid conditions of the study area), negative coefficients on COLD and COOL, and positive coefficients on WARM and HOT. The magnitude and significance of the coefficients should vary across crops.

Soil-Quality Variables

LNDCLASSA – Dummy variable that is 1 if the soil capability class is 2.25 or less (1 to 8 scale) and 0 otherwise.

LNDCLASSC – Dummy variable that is 1 if the soil capability class is 3.5 or greater (1 to 8 scale) and 0 otherwise.

SANDY – Dummy variable that is 1 if the soil type is 2.50 or less (1 to 5 scale) and 0 otherwise.

CLAYEY – Dummy variable that is 1 if the soil type is 3.75 or greater (1 to 5 scale) and 0 otherwise.

SLOPE – Average soil gradient in percent.

All soil-quality variables are average county values from the 1982 Natural Resources Inventory conducted by the Soil Conservation Service, USDA (Goebel and Dorsch, 1986). We expect that coefficients on the variables will be significant when crops have inflexible agronomic needs for certain soil conditions. Variables for land class and soil texture are constructed as dummy variables. Land Class B (2.25 to 3.5) serves as the omitted land class, with LNDCLASSA and LNDCLASSC serving as the extremes. As land classes tend to reflect soil productivity, the sign on LNDCLASSA should be positive and LNDCLASSC should be negative. Loamy soil is the omitted soil texture (2.5 to 3.75), with SANDY and CLAYEY serving as the extremes. SANDY and CLAYEY should typically have negative signs because they were defined to represent extreme conditions. Crops that either adapt easily to a variety of soil textures or prefer an extreme soil for agronomic reasons may be exceptions. For instance, rice plants prefer clayey soil while potatoes prefer sandy soil. Finally, in the observed range of the SLOPE data, topography of the land reflects the beneficial effect of slight slope, which promotes an even application of water, rather than the detrimental effect of extremely sloped topography.

Evaluating Orange Growers' Exercise of Market Power with Marketing Order Volume Control Regulations

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Abstract. *Previous studies have measured market power when firms consider the consequences of their actions on profits when deciding how much to produce or purchase, or both. In contrast, this study illustrates how to measure the exercise of market power when growers collectively control the quantities sold to a market use via a Federal marketing order but exert no control on the quantities produced. The hypothesis that California-Arizona navel orange growers exercised some market power (but not complete monopolistic power) before 1983 could not be rejected. Growers exercised less market power from 1983 on when a USDA policy change curtailed growers' use of marketing order volume controls.*

Keywords. *Market power, navel oranges, marketing orders, volume controls.*

An important aspect of public policy is detecting and limiting the exercise of significant market power by firms. A firm has market power when it can influence the price received for its output or the price paid for production inputs, or both. Deviations from competitive markets can distort incentives and redistribute benefits to firms who possess market power. Recognizing the importance of the detection problem, economists recently developed and extended techniques for measuring empirically a firm's exercise of market power (Bresnahan, 1989). Many case studies of the exercise of market power focused on apparent oligopolistic or oligopsonistic industries (Appelbaum, 1979; Appelbaum, 1982; Durham and Sexton, 1992; Holloway, 1991; Lopez, 1984; Porter, 1983; Schroeter, 1988; Schroeter and Azzam, 1990; Schroeter and Azzam, 1991; Sullivan, 1985; Sumner, 1981; Wann and Sexton, 1992). Few studies have measured the influence of public regulations on industry's exercise of market power. Those that have include studies of tomato marketing firms in Israel (Melnick and Shalit, 1985), celery growers in Florida (Taylor and Kilmer, 1988), and coconut oil processors in the Philippines (Buschena and Perloff, 1991).

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Some U.S. agricultural marketing programs can facilitate industry's exercise of market power. For example, the Capper-Volstead Act permits farmers to act together for marketing farm products (Heifner and Powers, 1992). The Agricultural Marketing Agreement Act (AMAA) of 1937, as amended, permits growers to determine collectively when, how much, and which produce can be shipped to selected markets, and to jointly raise funds for research and promotion (Heifner and others, 1981; Polopolus and others, 1986; Powers, 1990). The AMAA explicitly intended for growers to raise their prices collectively, and consequently, the act exempted growers from antitrust legislation.

This article illustrates how to measure the exercise of market power by growers who can influence quantities sold to selected markets via a Federal marketing order established under the AMAA. The Federal marketing order for California-Arizona (CA) navel oranges is a case study that authorized handler prorates, enabling the industry to establish a weekly maximum amount for shipment to a market use.

Previous studies have measured market power when firms consider the consequences of their actions on profits when deciding how much to produce. In these cases, the exercise of monopolistic market power is measured by estimating how much output prices exceed the marginal cost of production (Appelbaum, 1979; Appelbaum, 1982). In practice, this measurement involves specifying and estimating a demand for the output, cost function, input demands, and a profit condition. This study explores the measurement of market power in cases where growers collectively control the quantities sold to a market use but exert no control on the quantity produced. Measuring the exercise of market power derived via handler prorates, by contrast, entails estimating the extent to which growers equate marginal revenues in the regulated and nonregulated markets. The measurement of market power in this case involves specifying and estimating commodity demands for the output as well as a grower revenue condition.

Some studies analyzed the consequences of a hypothetical prorate suspension of CA navel or-

anges (Shepard, 1986; Thor and Jesse, 1981), while other studies explored selected aspects of actual prorate suspensions (Powers and others, 1986; Powers, 1991a and 1991b; Thompson and Lyon, 1989). None of these studies explicitly examined the exercise of market power by growers. The general structural model of this article, however, explicitly defines the interrelationships between growers' exercise of market power, quantity supplied to market uses, and demand parameters with market performance. Supplies for major market uses and prices are endogenous and determined simultaneously, rather than by predetermined or exogenous events. The model includes a parameter measuring the degree of market power exercised by growers. On the basis of this estimated parameter, various hypotheses about whether growers are price takers (not influencing prices in markets) or are maximizing revenue can be statistically tested. This parameter also permits tests of whether and to what extent major policy changes have affected growers' exercise of market power.

Institutions

The CA navel orange industry has operated a marketing order nearly continuously since 1933. The Navel Orange Administrative Committee (NOAC), composed of 11 growers and handlers and a consumer representative, manages the marketing order and votes on a handler prorate each week, which places an upper limit on the quantities handlers can ship for fresh-domestic use (the principal market). The regulations are binding on all handlers shipping navel oranges from the CA area.

Actual shipments for fresh-domestic use have nearly equaled the weekly prorate volume when prorates were administered, especially prior to the 1983 season when the NOAC administered nearly season-long prorates.[1] This observation suggests that prorates may have influenced annual volumes for this use. The amount exported and processed were unrestricted. The NOAC cannot set the price of fresh navel oranges but can influence it by adjusting the quantity that the industry sells for fresh-domestic use.

Growers can more easily influence price when the marketing order's coverage of the crop's growing area is more extensive. Growers covered by the marketing order for CA navel oranges supply about 75 percent of all domestically consumed fresh oranges during the winter season. Florida ships most of the remaining supplies of fresh oranges during this season. Unlike CA navel oranges, retailers and consumers squeeze some of Florida's fresh marketed oranges for fresh juice. Roughly 66 percent of the CA crop entered fresh-domestic use, 24 percent was processed, 8 percent was exported, and 2 percent filled other uses, such as donations and animal feed during the 1980's. Annual variation in the share of the CA crop to market uses is mostly between fresh-domestic use and processing.

The role of handlers is important because it can affect who obtains the benefits from market power derived from prorates. Growers without packinghouses contract with handlers who agree to grove pick, pack, and market navel oranges. Sunkist, a grower-owned marketing cooperative, has marketed about 65 percent of the CA crop since 1990, and more of the navel oranges grown in southern California than in central California. Southern California exported about 33 percent of its crop compared with about only 6 percent for central California during the mid-1970's to late 1980's. Despite these differences, the share of Sunkist's navel oranges shipped for fresh-domestic use and exports has nearly equaled the average for the industry (Mueller and others, 1987). Another marketing cooperative, Central California Orange Growers, has marketed about 20 percent of the crop during the 1990's. The remainder of the crop is marketed by proprietary handlers. Handlers sell fresh navel oranges to many buyers for regional and national wholesalers and retailers mostly on behalf of growers.

Does the dominant marketing cooperative possess monopolistic or monopsonistic power? It has monopolistic influence only when it can limit supplies sold in one or more markets and can exclude rivals from the market (Heifner and Powers, 1992). Sunkist does not satisfy these requirements (Mueller and others, 1987). An open-membership policy bars Sunkist from limiting growers' deliveries to packinghouses, and Sunkist cannot successfully influence f.o.b. prices by unilaterally limiting quantities sold to a market because other handlers and growers would benefit without bearing any of the costs. Sunkist's 1-year exclusive marketing contracts with growers and packinghouses appear necessary for efficient short-term marketing rather than excluding rivals. Sunkist also lacks monopsonistic influence because of its open-membership policy, and because higher net returns from marketing would be returned to

[1] The marketing season overlaps two calendar years. For example, the 1983 season began in fall 1982 and ended in spring 1983.

growers as higher prices or patronage refunds.[2] For these reasons, rival handlers would also have little monopolistic or monopsonistic power. The dominance of an open-membership cooperative suggests that handlers would pass any market power benefits derived from prorates back to growers in the form of higher net returns (grower prices plus patronage refund).

A General Model

NOAC administered season-long prorates over much of the period included in this analysis. For this reason, an annual model consisting of the major commodity demands for CA navel oranges along with a revenue condition was developed to help evaluate growers' exercise of market power. If adequate weekly data can be identified, the annual model could be extended to assess whether growers' exercise of market power varies within the season.

The quantity of fresh navel oranges demanded by domestic buyers is:

$$Q_f = f_1 (P_f, Z), \tag{1}$$

where Q_f is quantity for fresh-domestic use, P_f is the grower price of fresh navel oranges, and Z is a vector of exogeneous commodity demand-shifting variables.

The quantity of navel oranges demanded by processors is:

$$Q_p = f_2 (P_p, X), \tag{2}$$

where Q_p is quantity for processing, P_p is the grower price of navel oranges for processing, and X is a vector of exogenous commodity demand-shifting variables.

Navel oranges for processing are squeezed for juice and subsequently blended with other juices and sold as a fruit drink to consumers, and solids are made into jams. Consumers eat navel oranges for fresh-domestic use out-of-the-hand mostly at lunch or as a snack. Because of dissimilarities in end use, the markets for fresh use and processing are separate, setting up a prerequisite for successful price discrimination. Because the estimated coefficients are not different from zero at more than the 0.5 level of significance, the price of processed navel oranges does not appear in the fresh-domestic commodity demand, nor does the price of fresh navel oranges appear in the processing commodity demand (Shepard, 1986). The form of the growers' revenue condition becomes more complicated when commodity demands are interrelated.

Because quantities of navel oranges exported are relatively small, they are considered exogenous. That is, $Q_e = \tilde{Q}_e$, where Q_e is quantity exported and $\tilde{Q}_e$ is a constant.[3] Because they fetch the same price as navel oranges for fresh-domestic use and are unregulated, exports are important, particularly for southern California growers. The influence of exports on the exercise of market power, prices, and shipments for fresh-domestic use and processing is captured in the growers' revenue condition.

The small quantities of navel oranges for other uses are also considered exogenous, $Q_o = \tilde{Q}_o$, where Q_o is quantity for other uses and $\tilde{Q}_o$ is a constant. In contrast to exports, quantities to other uses earn nothing.

The market clearing identity is:

$$\tilde{Q} = Q_f + Q_p + \tilde{Q}_e + \tilde{Q}_o, \tag{3}$$

where $\tilde{Q}$ is quantity produced. Navel orange trees begin bearing some fruit 6-8 years after planting and continue bearing for 40-75 years. Given the physiological characteristics of this perennial tree crop, the assumption that the annual quantity produced is largely predetermined in the short run is reasonable for this analysis, which is based on a relatively short period.

Prorates enable growers to limit quantities sold for fresh-domestic use. Because exports do not expand much in the short run, some of the quantities of fresh-use quality oranges in excess of the prorated quantities may eventually enter processing. In this way, growers can influence how much goes to a given market. Growers exercising complete monopolistic power allocate a given quantity produced to maximize revenues, as in:

$$\begin{aligned} \mathcal{L} = \text{MAX } & P_f \{Q_f + \tilde{Q}_e\} + \\ & P_p \{\tilde{Q} - Q_f - \tilde{Q}_e - \tilde{Q}_o\}. \end{aligned} \tag{4a}$$

Exports earn the same price as navel oranges for fresh-domestic use, but quantities for other uses

[2] A reviewer pointed out that to the extent that Sunkist is more efficient than rivals, management may extract benefits from growers by authorizing perks.

[3] Export demand estimation was unsuccessful for several reasons. First, the composition of countries importing navel oranges has changed over time. The bulk of exports went to Europe before 1970. Since the mid-1970's, about 75 percent has gone to Japan, Singapore, and Hong Kong. Second, despite the gradual relaxation of Japanese citrus quotas, import duties remain.

are not included since they earn nothing. The growers' first-order condition, rearranged, is:

$$P_f + (\partial P_f/\partial Q_f)\,(Q_f + \tilde{Q}_e) = P_p + (\partial P_p/\partial Q_p)\,Q_p, \quad (4b)$$

where $(\partial P_f/\partial Q_f)$ is the first derivative of the inverse of the commodity demand for fresh-domestic use [equation 1 solved for P_f as a function of Q_f] with respect to Q_f, and $(\partial P_p/\partial Q_p)$ is the first derivative of the inverse of the commodity demand for processing [equation 2 solved for P_p as a function of Q_p] with respect to Q_p. Growers maximize revenues by allocating a given quantity of production (less quantities exported and for other uses) between fresh-domestic use and processing until the marginal revenues from sales to fresh uses (fresh-domestic use and exports combined) and processing are equal.

Growers may not be able to exercise complete monopolistic power for several reasons. First, because marketing opportunities are unevenly distributed across growing regions and marketing organizations (for instance, southern California growers export proportionately more navel oranges than others), NOAC members may be unable to agree on passing the prorate that maximizes industry revenues. Second, because the Secretary of Agriculture must approve the prorate before it becomes legally enforceable on all handlers, NOAC members may be reluctant to limit quantities sold for fresh-domestic use by the amount necessary for maximizing revenues. Rather than assume growers exercise complete monopolistic power via prorates, I attempt to measure the degree of market power (defined as the degree to which growers maximize revenues) actually exercised by growers. This can be done by first restating the first-order condition for growers exercising complete monopolistic power as $P_f - P_p = (\partial P_p/\partial Q_p)\,Q_p - (\partial P_f/\partial Q_f)\,(Q_f + \tilde{Q}_e)$, and then including a parameter β, as in:

$$P_f - P_p = \beta\,\{(\partial P_p/\partial Q_p)\,Q_p - (\partial P_f/\partial Q_f)\,(Q_f + \tilde{Q}_e)\}, \quad (5a)$$

where $\beta\,\{(\partial P_p/\partial Q_p)\,Q_p - (\partial P_f/\partial Q_f)\,(Q_f + \tilde{Q}_e)\}$ is the difference in grower prices in fresh use and processing attributable to growers' exercise of market power. β measures the degree of market power actually exercised by growers via prorates, and is implicitly affected by equity and political factors that the NOAC considers when making prorate decisions. β also measures the extent to which growers successfully maximize revenues via prorates. If $\beta = 1$, growers maximize revenues by equating marginal revenues for fresh use and processing as would a firm exercising complete monopolistic power without supply control. In a perfectly competitive market (where growers are price takers), $\beta = 0$, and prices in the two markets are equal. A β between 0 and 1 reflects various degrees of market power exercised by growers. A β closer to 1 reflects a greater degree to which growers maximize revenues.

The preceding approach does not require the explicit modeling of the prorate decision made by the NOAC. Rather, the degree of market power exercised by growers via prorates is inferred from actual market outcomes. The model incorporates factors the NOAC members discuss before voting on prorate, such as supply, demand, and price conditions.

The preceding approach requires that the product is homogeneous. If it is not, it can be difficult to differentiate accurately the effects of market power from quality variation in the price difference (equation 5a). Other studies have treated this issue casually or have incorrectly asserted that the (input or output) product is homogeneous. However, navel oranges are heterogeneous, and the effects of quality distinction must be sorted out from the exercise of market power in the price difference.

Navel oranges are preferred in fresh use because they are seedless and consumers can easily peel the rind. The low juice content of processed navel oranges lowers grower prices relative to those for fresh-use navel oranges. Navel oranges subsequently processed are profitable, despite negative grower prices, because they represent a part of the production base used in the marketing order from which the growers' prorate is calculated. (For a grower, a larger production base increases the maximum quantity of navel oranges eligible for shipment to the higher priced fresh-domestic use.) When the NOAC does not administer prorates, growers continue to pick navel oranges destined for processing to reduce insect and disease infestation of the groves. When the NOAC does not administer prorates, growers are price takers and profit incentives encourage growers and handlers to ship all navel oranges (which meet minimum fresh-use quality requirements and can be sold at a price covering marginal marketing costs) for fresh use. When growers are price takers, the prices in fresh use and processing are related, as in:

$$P_f - P_p = \delta + e, \quad (5b)$$

where δ is positive, reflecting the effects of quality distinction, and e is the residual term.

In contrast to the competitive market, revenue incentives encourage growers who administer

season-long prorates to restrict annual quantities sold to fresh-domestic use. Consequently, unpicked navel oranges deteriorate on the trees, so more would likely be processed than otherwise. This product diversion would increase the price difference above the level resulting from quality distinction when growers are price takers (equation 5b). The amount of the price difference above the amount for quality distinction represents the price effect from the exercise of market power (equation 5a). Thus, when the NOAC administers prorates, the price difference is composed of two parts: the quality distinction effect (as in equation 5b), and the market power effect (as in equation 5a). Combining these terms, the grower price difference is:

$$P_f - P_p = \delta + \gamma\{\beta[(\partial P_p/\partial Q_p)\ Q_p - (\partial P_f/\partial Q_f)\ \{Q_f + \tilde{Q}_e\}]\} + e, \tag{5c}$$

where γ is a binary variable that equals 1 when the NOAC administers prorates, and 0 otherwise.

The effect of quality distinction (that is, δ in equation 5c) could be estimated using observations during seasons the NOAC did not administer prorates. Unfortunately, the NOAC has not marketed navel oranges an entire season without administering prorates, so it is impossible to estimate the effect of quality distinction directly. Several approaches were explored to account for the effect of quality distinction indirectly. First, because the price difference is expected to narrow when the crop increases (more abundant supplies of fresh-use navel oranges), δ was specified as a function of total shipments of CA navel oranges. Second, δ was also specified as a function of the share of the CA crop for fresh use. In both cases, the estimated coefficient was not significantly different from zero at more than the 0.5 significance level. A trend variable to measure systematic changes in the price difference over time was no more successful at estimating δ.

In lieu of these findings, estimates of δ were provided by observing the range of real grower price differences during the weeks from 1983 to 1989 when the NOAC did not administer prorates. On this basis, in estimating equation 5c, δ was assumed to equal several values—\$2.00 (low value), \$2.75 (average value), and \$3.50 (high value) per carton of oranges. However, the price differences during the weeks' prorates were not administered and may not be entirely free from the influence of prorates.

Annual NOAC Bulletins were reviewed to identify events that likely created unusual crop quality conditions. A devastating freeze in 1968 created abnormal crop-quality problems, so a binary variable was included in equation 5c to account for the effect of a freeze on quality distinction.

The Empirical Model

The empirical estimation specifies explicit equations for the commodity demands (equations 1 and 2) and revenue condition (equation 5c). The revenue condition uses information from the inverse of the commodity demands, so the inverse of the commodity demands are specified. The inverse of the commodity demand for fresh-domestic use is:

$$P_f = a_0 + a_1\ Q_f + a_2\ Z + e_f, \tag{1'}$$

where a_0 is an intercept, a_1 and a_2 are estimated coefficients, and e_f is the error term. The equation is linear in coefficients and variables. The linear functional form was selected because the price flexibility was statistically less than 1 for the semi-logarithmic and double-logarithmic forms during some seasons. This finding suggests the unlikelihood that growers had restricted volumes for fresh-domestic use beyond the revenue-maximizing point.[4] The vector Z contains income and the price of fresh Florida oranges (Powers, 1991a; Shepard, 1986). Prices or quantities of grapefruit, bananas, and apples and prices of marketing inputs (transportation and labor costs) were omitted from the vector Z because each of the estimated coefficients was not different from zero at more than the 0.6 significance level. This omission did not affect the estimated coefficient for Q_f, so critical findings about β in equation 5c are unaffected. The price rather than the respective quantities of Florida oranges was included because the explanatory power of the equation was larger.

The inverse of the commodity demand for processing is linear in coefficients and variables as:

$$P_p = b_0 + b_1\ Q_p + b_2\ X + e_p, \tag{2'}$$

where b_0 is an intercept, b_1 and b_2 are estimated coefficients, and e_p is the error term. The vector X includes income and the price of Florida oranges for processing (Powers, 1991a; Sheppard, 1986). Prices or quantities of grapefruit juice and apple juice were omitted from the vector X because each of the estimated coefficients was not different from zero at more than the 0.6 significance level.

[4]The estimated degree of market power exercised by growers was not sensitive to the three functional forms for the inverse commodity demand as indicated by stable estimated values of β in equation 5c.

The relationship between the endogenous quantity variables (Q_f and Q_p) and the exogenous quantity variables is given by the market-clearing identity, restated as:

$$Q_p = \tilde{Q} - \tilde{Q}_e - \tilde{Q}_o - Q_f. \qquad (3')$$

Using information from equations 1' and 2', the growers revenue condition is:

$$P_f - P_p = \delta + c_o \text{ FREEZE} + \beta [b_1 Q_p - a_1 (Q_f + \tilde{Q}_e)] + e_\beta, \qquad (4')$$

where c_o is an estimated coefficient and e_β is the residual. The binary variable FREEZE accounts for the effect of a freeze on crop quality and thus on the price difference. Using estimates of a_1 and b_1 from equations 1' and 2', β is identified in equation 4'.

Growers administered season-long prorates for many years, until 1983, when USDA encouraged growers to limit the number of weeks with prorate in place. Thereafter, the NOAC administered prorates until 60-75 percent of the crop had been marketed. To account for the potential impact of this policy change, β was specified as:

$$\beta = \beta_0 + \beta_1 D_{1983}, \qquad (5')$$

where β_0 is an intercept, β_1 is an estimated coefficient, and D_{1983} is a binary variable that equals 1 from 1983 on.[5] Because growers had less ability to influence seasonal quantities for market uses from 1983 on, the expected sign of β_1 is negative.

To account for inflation and population changes over time, the prices in equations 1' and 2' were inflation-adjusted and the quantities in equations 1'-3' were in per capita. Equation 4', thus, is in terms of per capita and real prices.[6]

Data

USDA establishes annual prices for fresh and processed CA navel oranges, and fresh and processed Florida oranges. Each price is an average of within-season grower prices weighted by the corresponding within-season shipments. The prices of fresh and processed Florida oranges include Florida's early, midseason, and Valencia oranges.

Quantities of CA navel oranges for fresh-domestic use, processing, exports, and other uses are from annual NOAC reports, on a per capita basis. The Economic Research Service, USDA, furnished U.S. population data as of January 1. Disposable income data are from the U.S. Department of Commerce. All prices and income were inflation-adjusted by dividing the respective variables by the consumer price index (CPI) (1982-84 = 1.00) for all items. CPI's are from the U.S. Department of Labor. The observations cover 1965-89. Table 1 shows the mean and standard deviations for the variables.

Findings

Do growers exercise market power? Did the degree of market power exercised by growers change when prorate use was curtailed in 1983? To answer these questions, equations 1' and 2' were estimated first by using two-stage least squares (2SLS), and then were inserted the unbiased estimates of a_1 and b_1 into equation 4'. Equation 4' subsequently was estimated by 2SLS.

Table 2 shows the estimated coefficients, corresponding standard errors, and level of significance for the two price-dependent commodity demands. Each of the estimated coefficients for the inverse commodity demand for fresh-domestic use have the expected signs, and most are different from zero at

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[5] The Cost of Living Council pressured the NOAC to increase prorate quantities during the latter part of the 1974 season. A binary variable for the 1974 season was included in preliminary specifications of equation 5c to account for the potential impact of this policy change. But, it was excluded because the estimated coefficient was not different from zero at even the 0.5 significance level.

[6] Growers are interested in maximizing industry revenue, not real per capital revenue. The two are equivalent. The objective for growers maximizing total revenue is:

$$\mathscr{L} = \text{MAX } P_f (Q_f + \tilde{Q}_e) + P_p (\tilde{Q} - Q_f - \tilde{Q}_o),$$

where the P's are nominal prices and the Q's are shipments. And, the first-order condition for growers maximizing total revenue is:

$$P_f + (\partial P_f/\partial Q_f) (Q_f + \tilde{Q}_e) - P_p (\partial P_p/\partial Q_p) Q_p = 0.$$

The objective for growers maximizing total revenue can be restated as:

$$\mathscr{L} = \text{MAX POP CPIA } [P_f (Q_f + \tilde{Q}_e) + P_p (\tilde{Q} - Q_f - \tilde{Q}_e - \tilde{Q}_o)],$$

where the P's now are inflation-adjusted prices, the Q's now are per capita quantities, POP is population, and CPIA is the inflation-adjusting index. The first-order condition for growers maximizing total revenue in this case is:

$$\text{POP CPIA } [P_f + (\partial P_f/\partial Q_f) (Q_f + \tilde{Q}_e) - P_p + (\partial P_p/\partial Q_p)] = 0,$$

which, by division, is equivalently:

$$P_f + (\partial P_p/\partial Q_f) (Q_f + \tilde{Q}_e) - P_p + (\partial P_p/\partial Q_p) Q_p = 0.$$

Thus, maximizing total revenue implies maximizing real per capita revenue.

Table 1—Means and standard deviations, 1965-89 annual data

Variables	Mean	Standard deviation
Endogenous:		
Real grower price for fresh CA navel oranges ($/37.5-lb. carton)	4.17	1.37
Real grower price for processed CA naval oranges ($/carton)	–0.38	0.47
Quantity of CA navel oranges for fresh-domestic use (cartons per million U.S. persons)	158,665	33,976
Quantity of CA navel oranges for processing (cartons per million U.S. persons)	56,762	25,099
Exogenous:		
Real grower price for fresh Florida oranges ($/90-lb. box)	6.03	1.87
Real grower price for processed Florida oranges ($/box)	4.88	1.40
Total quantity of CA navel oranges (cartons per million U.S. persons)	237,526	60,786
Quantity of CA navel oranges for exports (cartons per million U.S. persons)	15,857	8,240
Quantity of CA navel oranges for other uses (cartons per million U.S. persons)	6,241	1,940
Real U.S. disposable income (dollars per capita)	9,866	1,133

Table 2—Two-stage least squares estimates, 1965-89 annual data

Item	Coefficient	Asymptotic standard error
Inverse commodity demand for CA navel oranges for fresh-domestic use:		
Intercept	8.235	0.892*
Quantity of CA navel oranges for fresh-domestic use	–0.000036	0.000005*
Real grower price for fresh Florida oranges	0.207	0.058*
Real U.S. disposable income	0.0001	(0.00004)
Correlation between predicted and actual values = 0.942		
Durbin-Watson = 1.370		
Inverse commodity demand for CA navel oranges for processing:		
Intercept	0.714	0.525
Quantity of CA navel oranges for processing	–0.000004	0.000002*
Real grower price for processing Florida oranges	0.213	0.043*
Real U.S. disposable income	–0.00019	0.00005*
Correlation between predicted and actual values = 0.831.		
Durbin-Watson = 1.876.		

*Signifies that the estimated coefficient is different from zero at the 0.1 significance level.

conventional levels of significance. The correlation of the predicted and actual prices of fresh navel oranges is 0.942. The Durbin-Watson statistic is 1.370 and does not indicate a first-order autocorrelation scheme in the errors. Each of the estimated coefficients for the inverse commodity demand for processing display the expected signs and all are different from zero at conventional levels of significance. Income's negative influence may reflect a consumer switch from fruit drinks (made with processed navel oranges) to juices, such as orange or grapefruit, as disposable income increases. The correlation of the predicted and actual prices for processed navel oranges is 0.831. The Durbin-Watson statistic is 1.876, suggesting the absence of first-order autocorrelation in the residuals.

Table 3 summarizes results from the price difference equations. Each of the estimated coefficients exhibits the expected sign, and all are different from zero at conventional levels of significance. The estimates of the β's vary slightly for the assumed values of δ but are consistent in two ways. First, the estimates of β before 1983 (β_o) are positive and less than 1. Second, the estimates of the change in β from 1983 on (β_1) are negative.

The estimated coefficient for β before 1983 (that is, prior to the curtailment of prorate use) is 0.441 with a 95-percent confidence interval of 0.350 to 0.532 when δ = 2.00, 0.312 with a 95-percent confidence interval of 0.228 to 0.395 when δ = 2.75, and 0.182 with a 95-percent confidence interval of 0.105 to 0.259 when δ = 3.50. Because these confidence intervals are between 0 and 1, price-taking behavior and the exercise of complete monopolistic power are both rejected. On this basis, the hypothesis of growers exercising some monopolistic power before 1983 is not rejected.

The policy change in 1983 provided an opportunity to test whether growers exercised less market power from 1983 on when prorate use was curtailed. Growers' exercise of market power fell from 1983 on (β_1 = –0.206 when δ = 2.00, β_1 = –0.176 when δ = 2.75, and β_1 = –0.145 when δ = 3.50). The estimate of growers' exercise of market power from 1983 on ($\beta_o + \beta_1$) is 0.235 when δ = 2.00, 0.136 when δ = 2.75, and 0.036 when δ = 3.50. The hypothesis that growers exercised complete monopolistic power from 1983 on is rejected at more than the 0.05 level of significance, based

Table 3—Two-stage least squares estimates, 1965-89 annual data[1]

Item	δ = 2.00 Coefficient (Asymptotic standard error)	δ = 2.75 Coefficient (Asymptotic standard error)	δ = 3.50 Coefficient (Asymptotic standard error)
Growers' exercise of market power (price difference):			
Freeze	5.792	5.299	4.806
	(1.096)*	(1.012)*	(0.931)*
β_0	0.441	0.312	0.182
	(0.046)*	(0.043)*	(0.039)*
β_1	–0.206	–0.176	–0.145
	(0.071)*	(0.066)*	(0.060)*
Correlation between predicted and actual values	0.575	0.636	0.694

[1]The Durbin-Watson is not reported because it is not valid in equations without an estimated intercept. A comparable test, in this case, is to regress the residuals for this equation against the 1-year lag of residuals and test the estimated coefficient for significance from zero. The absolute value of the t-ratio for the coefficient for the lag of residuals was less than 0.3, suggesting the absence of first-order autocorrelation.

*Signifies that the estimated coefficient is different from zero at the 0.1 level of significance.

on calculated t-ratios for complete monopolistic power from 1983 on ($\beta_o + \beta_1 = 1$) of –8.966 when δ = 2.00, –10.971 when δ = 2.75, and –13.291 when δ = 3.50. And, based on calculated t-ratios for price taking from 1983 on ($\beta_o + \beta_1 = 0$) of 2.751 when δ = 2.00, 1.721 when δ = 2.75, and 0.487 when δ = 3.50, the hypothesis that growers were price takers from 1983 on is rejected at the 0.05 significance level if δ = 2.00 or 2.75 but not if δ = 3.50.

Estimating equations 1', 2', and 4' by three-stage least squares (3SLS) can improve the efficiency of the estimated parameters. Because of convergence problems, the estimated coefficients for a_1 and b_1 were constrained to equal the unbiased estimates from 2SLS when estimating the equations by 3SLS. Table 4 contains estimated results for 3SLS when δ = 2.75. The results for the 3SLS and findings about market behavior were consistent with the results from 2SLS.

Some Impacts of the Marketing Order

Using the estimates of the model's demand parameters and values for the exogenous variables, prices, quantities, and revenues can be solved for the unrestricted use of prorate, restricted use of prorate, and competitive cases. Solving for market performance in the three cases involved using values of the exogenous variables during 1989 and the parameters estimated by 3SLS when δ = 2.75.

When growers' use of prorate is unrestricted ($\beta = \beta_o$), an estimated 56.7 percent of the crop fills fresh-domestic use, 30.9 percent is processed, 9.7 percent is exported, and 2.7 percent fills other uses. The estimated real prices of fresh and processed navel oranges are \$4.21 and –\$0.60 per carton. Estimated real industry revenue is \$184 million. When growers' prorate use is restricted ($\beta = \beta_o + \beta_1$), an estimated 66.3 percent of the crop fills fresh-domestic use and 21.3 percent is processed. Shares to exports and other uses are similar to shares under unrestricted use. The estimated real prices of fresh and processed navel oranges are \$3.22 and –\$0.49 per carton and estimated real industry revenue is \$165 million (\$18.7 million less than if growers prorate use is unrestricted). In the competitive case ($\beta = 0$), an estimated 74.6 percent of the crop fills fresh-domestic use and 13 percent is processed. The estimated real prices of fresh and processed navel oranges are \$2.36 and –\$0.39 per carton and estimated real industry revenue is \$137.1 million (\$46.9 million less than if growers' prorate use is unrestricted).

Figure 1 illustrates marketing order effects on prices and shipments for fresh-domestic use and processing. In the competitive case, $\tilde{Q}_f$ goes for the fresh-domestic use and $(\tilde{Q} - \tilde{Q}_f)$ is processed. The price difference is δ. In contrast, growers who maximize industry revenue move along the marginal revenue schedules for the commodity demands and equate marginal revenues by shipping only Q_f^* for fresh-domestic use but $(\tilde{Q} - Q_f^*)$ for processing. The price of fresh navel oranges is higher when growers exercise monopolistic power, but the price of processing navel oranges is lower.

Conclusions

This article's structural model illustrates how to measure the exercise of market power by growers who can influence the quantities shipped for a market use. The hypothesis that growers exercised some market power via marketing order prorates (but not complete monopolistic power) prior to 1983 could not be rejected. Growers appear to have exercised less market power from 1983 on, which coincides with a policy curtailing growers' use of prorate.

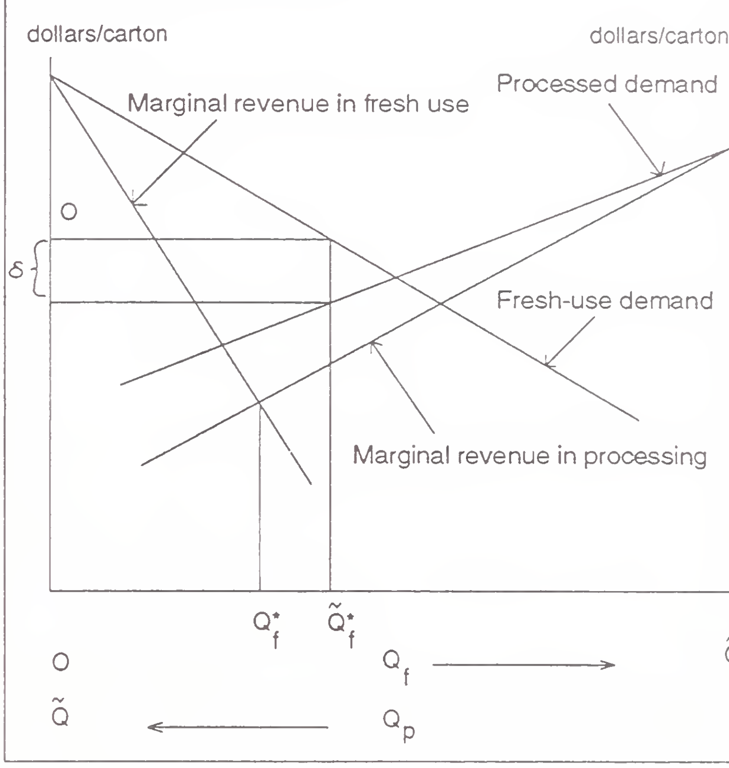
Table 4—Simultaneous equation estimates for δ = 2.75, 1965-89 annual data

Item	Coefficient	Asymptotic standard error
Inverse commodity demand for CA navel oranges for fresh-domestic use:		
Intercept	8.277	0.779*
Quantity of CA navel oranges for fresh-domestic use	−0.000036	
Real grower price for fresh Florida oranges	0.184	0.045*
Real U.S. disposable income	0.00005	0.00007
Correlation between predicted and actual values = 0.942, Durbin-Watson = 1.366		
Inverse commodity demand for CA navel oranges for processing:		
Intercept	0.606	0.459
Quantity of CA navel oranges for processing	−0.000004	
Real grower price for processing Florida oranges	0.253	0.034*
Real U.S. disposable income	−0.0002	0.00004*
Correlation between predicted and actual values = 0.829, Durbin-Watson = 1.992		
Growers' exercise of market power (price difference):		
Freeze	4.241	0.762*
β_0	0.319	0.038*
β_1	−0.192	0.053*
Correlation between predicted and actual values = 0.597, Durbin-Watson[1]		

[1]The Durbin-Watson is not reported because it is not valid in equations without an estimated intercept. A comparable test, in this case, it to regress the residuals for this equation against the 1-year lag of residuals and test the estimated coefficient for significance from zero. The absolute value of the t-ratio for the coefficient for the lag of residuals was less than 0.3, suggesting the absence of first-order autocorrelation.

*Signifies that the estimated coefficient is different from zero at the 0.1 significance level.

Figure 1
Prices and quantities



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Food Safety: Economists Take a Bite

Economics of Food Safety. *Edited by Julie A. Caswell. New York: Elsevier Science Publishing Co., 1991, 356 pages, $135.*

Reviewed by Phil R. Kaufman

This collection of articles provides economists and policymakers with many of the tools necessary for understanding the potentially volatile issue of food safety. Although falling short as a textbook source, as the title may imply, the collection of articles nevertheless is an ambitious beginning toward understanding the conceptual and empirical complexities of the economics of food safety. The work also reveals weaknesses that subsequent researchers must address. Policymakers should also value the contributions made here but should recognize the limitations of current research. Greater demand for food safety policy will result in an equally large research supply response.

The editor, an economist, chose to organize individual chapters into sections that address either the demand for or the supply of food safety and quality. Lay readers and policymakers may not appreciate that scheme, however. In addition, a number of authors address research methodologies as opposed to the purely applied empirical aspects of food safety analysis.

Smallwood and Blaylock assess the suitability of economic concepts and methods for analyzing food safety issues in the lead chapter. They review models and applications of demand analysis to food safety issues, including household production models, product characteristics, and attribute models. Sufficient theoretical foundations of consumer behavior exist to adequately address many food safety issues, but empirical application is data intensive, and therefore demanding of the researcher. Smallwood and Blaylock conclude that, as a result, most studies provide only a weak link between analytical results and theoretical constructs. However, the chapter falls short by not addressing the obvious need for better data sources.

Two chapters address the element of risk in consumer food demand models. Choi and Jensen find that perfectly competitive markets would provide complete information about food substance hazards, allowing for a socially optimal level of food safety. The role of the Government is to ensure that food safety and risk-related information are accurate. Falconi and Roe, on the other hand, assert that such information would exist as a public good, rather than a private good. As such, the private provision of food hazard and health risk information would be reduced to the lowest common denominator across competing firms. Because there are no incentives for individual suppliers to alter their allocation of a food substance (ingredient or additive), neither total industry allocation nor product price is affected. The reader is left to reconcile the seemingly conflicting conclusions.

Extending consumer demand methodologies to incorporate risk first requires that it be properly measured. Carriquiry and others review methodologies for determining exposure to health risks, distinguishing between short-term (acute) and long-term (chronic) risk exposure. This characteristic may be useful to help explain why the public's perceived health risks often differ from science-based risk measures, given the significance of chronic conditions. Relative risk assessment extends to evaluating food hazard control strategies. Curtin and Krystynak apply this approach to the Canadian poultry processing industry in which the costs of intervention at various stages of production and distribution are estimated and compared with potential benefits. Although cost-effective, their proposal would likely conflict with existing food safety standards and regulations, making implementation impractical.

A number of articles are devoted to understanding consumer demand for greater food safety and risk-reduction behavior. Van Ravenswaay and Hoehn analyzed apple consumption during the Alar controversy in 1984-89. The authors found that demand for apples declined in 1984 after the Environmental Protection Agency issued a new risk assessment of Alar (a growth regulator), and not after heightened media activity in 1989, which contrasts popular perception.

Awareness about the use of pesticides, especially in fresh fruit and vegetable production, has nevertheless triggered a growing interest in consumers' willingness to pay for food safety assurance, and of the apparent credibility gap among government agencies charged with monitoring and regulating chemical use. Ott and others found that consumers prefer independent laboratories to government agencies for pesticide residue tests. The

[1]Kaufman is an agricultural economist in the Commodity Economics Division, ERS.

credibility issue is central to the consumer acceptance of the production-enhancing BSt hormone in milk, according to Preston and others. Neither of the chapters develops the economic implications of identified risk behavior, however. Attention should also have been given to the new bio-engineered food products and their potential for success in view of apparent consumer skepticism. Many studies of the consumer demand response to food safety and health information, such as "willingness to pay" surveys, have relied on hypothetical situations. The degree to which these controlled experiments approximate actual consumer tastes and preferences in the marketplace is debatable.

A final set of articles is devoted to private and public food safety strategies. Caswell and Johnson distinguish between individual firm strategies according to their purpose: differentiation strategies attempt to improve a competitive position; risk management strategies attempt to minimize liability resulting from a hazardous product or violation of government regulation; and proactive strategies attempt to guide the regulatory process in the best interests of the firm. The authors present a number of case studies involving agricultural producers, food processors, and retailers. The Caswell and Johnson article lacks for empirical support that would quantify the returns to food safety strategies. Clearly, the decision to implement a given strategy should take into account tangible and intangible costs and benefits. Because differentiation strategies constitute firm or product differentiation, how does one disaggregate the costs and returns of the multiple strategies involved? Finally, to what extend do private initiatives substitute for greater government oversight and regulation. From a social welfare perspective, which approach—public or private—best addresses food safety and health risks?

French and Neighbors offer essentially an accounting model for determining the firm costs of food labeling compliance, an important policy consideration. Mauskopf and Chapman attempt to improve the efficiency of the imported foods enforcement program. They develop a model of firm compliance behavior given a dynamic enforcement program. Product sampling rates are thus adjusted to minimize program costs and maximize firm compliance. While superior to the existing dynamic sampling approach, successful implementation may hinge on fairness and equity issues raised by the firms subject to enforcement.

The *Economics of Food Safety* contains a collection of literature addressing the conceptual and empirical issues that will likely give considerable value to the uninitiated researcher, so I would recommend the book to all who wish to better inform themselves in this emergency area.

On the Jobs

Multiple Job-holding among Farm Families. *Edited by M.C. Hallberg, Jill L. Findeis, and Daniel A. Lass. Ames: Iowa State University Press, 1991, 350 pages, $41.95.*

Reviewed by Leslie A. Whitener

This anthology evolved from a May 1988 symposium on multiple job-holding among farm families, sponsored jointly by the four Regional Rural Development Centers and the Farm Foundation. The book is designed as a guide to research and policy responses to the phenomenon of part-time farming and multiple job-holding among U.S. and Canadian farm families. Twenty-one papers by agricultural economists, rural sociologists, anthropologists, extension specialists, and rural development experts are organized into six major sections: historical perspective and future prospects; current theoretical issues; results of farm household surveys; rural labor market factors; public programs for multiple job-holding farm families; and policy issues and research needs.

This collection offers a comprehensive review of multiple job-holding of farm families. And while it is a "must read" for anyone about to embark on research studies in this area because it succinctly reviews the progress to date, it is far more useful for illustrating where we have been than for suggesting where we should go. In fact, the book debates, but never really answers, the question of why we should go anywhere.

The various articles differ in quality, research approach, and analytical technique, but the anthology draws strength from this multidisciplinary perspective. Anthropologist Peggy Barlett bases her findings about the motivations of part-time farmers on participant observation and open-ended, in-depth interviews with a small number of farm families in Dodge County, Georgia. Although geographically limited, her excellent case study

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points to the multitude of economic and noneconomic factors affecting farm families' career decisions, including lifestyle aspirations, farm background, attitudes toward farming, parental attitudes and expectations, enjoyment of farmwork, available land and capital resources, and off-farm job opportunities.

Economists and sociologists examine the theoretical underpinnings for much of the empirical work on multiple job-holding among farm families. Economist Wallace Huffman presents an agricultural household economic model that combines the agricultural producer, consumer, and labor-supply decisions of farm households into a single conceptual framework. He draws from econometric studies in both Canada and the United States to illustrate the utility of the model for understanding off-farm labor demand and supply. A worthwhile companion to this piece is the article by Daniel Sumner, which suggests refinements and new directions for econometric modeling. Sumner, for example, argues that researchers may miss part of the story by simply modeling off-farm work as a choice made after the decision to farm. He argues that research should address the self-selection of farmwork by nonfarmworkers as well.

Several farm household surveys (in multicounty areas of Illinois, Wisconsin, Louisiana, and Florida) ground the more theoretical chapters. Christina Gladwin explores the relationship between multiple job-holding and the increase in women's farming in Florida. She concludes that women on part-time farms now do more of the farming because "they are stepping in and substituting for their husbands, more of whom must now work off the farm at a high-paying job to subsidize the farm operation and keep the family's living standard at an acceptable level." In my view, far too little research has focused on farm women and their changing roles on and off the farm, and the Gladwin study is most welcome.

The book draws from academicians, extension specialists, and rural development experts to help place part-time farming within the context of public policy decisions. Kenneth Deavers points out that rural development policy and farm policy are not synonymous and argues that rural development programs are likely to have little effect on farm financial stress or poverty among households operating small farms. The most successful economic development programs, he notes, will promote the development of infrastructure and communications to move ideas and information rather than to move people.

Common themes emerge despite the diversity of perspectives. Multiple job-holding is not just a transitional phenomenon experienced by those entering or leaving farming, but a more permanent and widespread occurrence that enables many farm families to pursue a chosen lifestyle, main-

The papers are: (1) "Multiple Job-holding among Farm Operator Households in the United States" by Mary Ahearn and John E. Lee, Jr.; (2) "Multiple Job-holding among Farm Families in Canada" by Anthony M. Fuller; (3) "Motivations of Part-time Farmers" by Peggy F. Barlett; (4) "Multiple Job-holding in Perspective: A Discussion" by Paul W. Barkley; (5) "Agricultural Household Models: Survey and Critique" by Wallace E. Huffman; (6) "Efficiency Aspects of Part-time Farming" by Ray D. Bollman; (7) "Modeling On-farm Enterprise Adjustments" by Thomas A. Carlin and Susan Bentley; (8) "Useful Directions for Research on Multiple Job-holding among Farm Families" by Daniel A. Sumner; (9) "Evolving Dimensions of Dual Employment of Illinois Farm Families" by R.G.F. Spitze and R.K. Mahoney; (10) "Multiple Job-holding among Farm Families: Results from the Wisconsin Family Farm Surveys" by William Saupe and Brian W. Gould; (11) "Off-farm Employment Participation in Louisiana: An Analysis of Survey Results" by Tesfa G. Gebremedhin; (12) "Multiple Job-holding among Farm Families and the Increase in Women's Farming" by Christina Gladwin; (13) "The Future Role of Farm Household Surveys: A Discussion" by Mary Ahearn; (14) "Factors Affecting the Supply of Off-farm Labor: A Review of Empirical Evidence" by Daniel A. Lass, Jill L. Findeis, and Milton C. Hallberg; (15) "Effects of Location on Off-farm Employment Decisions" by Jill L. Findeis, Daniel A. Lass, and Milton C. Hallberg; (16) "The Market for Farm Family Labor" by Thomas G. Johnson; (17) "Traditional Farm Commodity Programs and Multiple Job-holding by Luther Tweeten; (18) "Rural Development and the Well-being of Farm Families" by Kenneth L. Deavers; (19) "Extension Programs and Policies for Part-time Farmers" by James C. Barron; (20) "Public Programs for Multiple Job-holding Farm Families: Discussion" by Lionel Williamson; (21) "Policy Issues and Research Needs" by R.J. Hildreth.

tain a rural residence, or meet other personal and financial goals. These findings argue against the common perception that multiple job-holding is a phenomenon based solely on economic hardship. The symbiotic relationship between agriculture and the nonfarm economy is another theme. Many farm families depend heavily on the jobs, business and social services, market outlets, and inputs provided by the nonfarm sector. At the same time, the rural nonfarm sector could not exist without the farming community and its surplus labor, service sector needs, and social and economic institutions. Also, Mary Ahearn and John Lee discuss data limitations and the problems associated with classifying part-time farmers using income-based measures, hour-based measures, or a combination approach. Their definitional and data concerns are echoed as a theme throughout the book.

Research studies examining multiple job-holding in Canada are an asset to the book, demonstrating its similarities to U.S. agriculture. In both Canada and the United States, most farms are private family enterprises; agriculture is highly developed and relatively capital-intensive; multiple job-holding among farm households is the norm rather than an aberration; resources are mobile between farm and nonfarm sectors; and the farm families' decision to go part-time depends on economic, social, and structural reasons.

The objectives of the book are nicely elucidated, but the rationale is elusive. The authors repeatedly ask, "Why study part-time farmers?" (Barlett), "What are the problems ... and who cares?" (Carlin and Bentley), and "Are we a conference looking for an objective?" (Hildreth). The repetitiveness of their queries underscores the amorphous nature of multiple job-holding research. Also, readers need help to synthesize the results and conclusions for 21 theoretical and empirical chapters. A concluding chapter that summarized findings and elaborated on future research and policy directions would have been most welcome.

This compendium explores little new ground. Yet, it lays important groundwork for future studies of the causes and consequences of multiple job-holding among farm families, and in this regard, makes an important contribution to the agricultural literature.

Mathematical Programming: Tinker Toys with a Purpose

Economic Logistics: The Optimization of Spatial and Sectoral Resource, Production, and Distribution Systems. *By Sten Thore. New York: Quorum Books, 1991, 360 pp., $49.95.*

Reviewed by David Letson

Mathematical programming texts are often heavy on technique but light on synthesis and imagination. Given a menu of model types, readers must discover the usefulness of each. Wading through this sort of presentation can be like reading a dictionary—all parts, no assembly instructions. Such texts are less likely to promote research-bearing economic insight than to provide toys for the academic sandbox. Sten Thore's mathematical programming text is refreshingly different, an engaging presentation of the basic methods, with an important advantage. His synthesis of basic model types also describes the chain of optimization behavior in an economic sector. Far from a cookbook of techniques, the text presents an economic theory for market formation that provides students and professionals with a better appreciation of basic modeling.

The strength of the text is its synthesis. Thore's convincing thesis is the usefulness of linking basic model types. The resulting concatenation is "economic logistics," the analysis of resource, production, inventory, and distribution systems. Most importantly, he joins the transportation problem, activities analysis, and the warehouse problem. The transportation problem traces the spatial movement of goods from production to retail outlets. Activities analysis considers the constituent stages or "activities" of production wherein raw materials are converted first to intermediate and then to final goods. The warehouse problem uses inventories to smooth the time paths of inputs and outputs. Combining the first two model types allows analysis of spatial flows of commodities through a production chain. Linking the transportation and warehouse problems leads into the analysis of regional warehouse systems. Joining activities analysis and the warehouse problem enables a look at multistage warehouse systems of intermediate goods coming into the production and distribution of final goods. The result of this synthesis is a compelling portrait of

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the economic sector as a chain of optimizing behavior that solves for optimal market prices and quantities. Numerous examples and exercises emphasize the usefulness of this set of tools in transforming empirical observations into economic insights of practical concern.

One weakness of the text is that Thore's initial models, the building blocks for his synthesis, are intentionally basic. Compared with other mathematical programming texts (for example, Hazell and Norton, 1986[1]), the material here is older. Thore's choice of material does facilitate his synthesis, but limits much of the discussion to fairly simple models. This shortcoming is minor, though, because students would do well to think creatively with these time-honored methods before moving on to more advanced ones. Thore does provide references to newer material and, with his bibliographic notes, excellent historical documentation. He also acknowledges limitations of the material. For example, the Takayama-Judge extension of Samuelson's spatial equilibrium analysis to multiple commodities is dismissed as artificial because of its assumption of symmetric demand and supply-price coefficients. A more serious drawback of the book is its failure to discuss solution algorithms. That omission is inconsistent given Thore's advocacy of basic models, suggesting that researchers benefit from intimate familiarity with their models but not from familiarity with the ways these models are solved. He does credit advances in software and hardware that have made nonlinear programming a practical tool for the classroom (p.11), but then abandons the subject.

Thore's intended audience goes beyond the graduate classroom to economists who have not realized the full strength of the tools of mathematical programming developed over the last fifty years. Techniques such as chance-constrained programming and goal programming (developed by Thore's sometimes collaborators, A. Charnes and W.W. Cooper) can provide economics with the operational significance it needs, Thore argues. His book both explains and advocates mathematical programming. The joining of purposes is fitting since he wants to give all a greater appreciation for the power of mathematical programming. Students must learn what professionals should relearn.

Economic Logistics applies mathematical programming to a wide range of economic problems, from the regulation of whaling to the manufacture of personal computers. For agricultural economics instructors, the general presentation can be both a strength and a weakness. Both the breadth and technical clarity of the book are clear advantages. Saddle point theory and game theory, for example, receive explanations for the novice. As a general economics text, however, the reader finds fewer specific applications to farm modeling, as compared with alternatives, such as Hazell and Norton's text. In particular, Thore relies on a single technique (chance-constrained programming) to model risk, which is more acceptable for students in economics than in agricultural economics, where risk receives greater emphasis. Instructors using Thore's text for agricultural economics gain the generality of his scope but may need supplementary readings to cover the range of risk-modeling techniques and specific farm models.

Thore is at bottom an eclectic. His basic curiosity of how modern economies function motivates diverse discussions of mathematical programming and economic theory toward the end of the book. These discussions add flesh to his synthesis and display the operational capability of the material. For example, Thore sees surpluses of agricultural commodities and unemployed labor as disequilibria and models them with price constraints. His labor market example is decidedly unconventional since its objective function maximizes the *ex ante* value of unemployed labor. In another discussion, he invokes chance-constrained programming to model technological change, which occurs today, he argues, via small, predictable jumps in productivity, rather than the large leaps that Schumpeter described in his day (and that would invalidate such a modeling approach). The last chapter describes bidding behavior as an infinite game to incorporate uncertainty about competitors and market reactions. With these discussions, Thore offers what countless economists have offered before him: a vision of how markets form.

Good modelers are technically competent and imaginative. *Economic Logistics* is both, which is why I recommend it despite minor criticisms. Thore offers mathematical programming as inventive, unconventional microeconomic theory. He uses language much like Wassily Leontief and Frederick Waugh in describing what he thinks economists should do. His economics is an aggregation of models of individual producers, shippers, and warehouses, forming a logistical system that solves for optimal market prices and quantities. He argues that economists are not enough concerned with the operational significance of relevant economic questions. His insights motivate the

[1]Peter B.R. Hazell and Roger D. Norton. *Mathematical Programming for Economic Analysis in Agriculture, New York: Macmillan, 1986.*

reader, for technique alone is hardly economics, let alone good reading. For the graduate classroom, *Economic Logistics* provides a synthesis of basic mathematical programming with an imaginative demonstration of its capabilities. For the rest of us, it is a reminder of tools developed over the past half-century and their power when in creative hands.

Unheeded Prophecies or Misguided Meanderings?

Environmental Policy and the Economy. *Edited by F.J. Dietz, F. van der Ploeg, and J. van der Straaten. Amsterdam: North-Holland, 1991, 331 pages, $69.50.*

Reviewed by John K. Horowitz

This collection of articles made me fear for the earth's survival. But, should I? According to the authors, environmental problems and the inability of economies to deal with them seem to be leading to a great catastrophe. Yet, it's striking how little of the economy is actually affected by environmental problems. There are exceptions, of course, such as the pollution of the Aral Sea in Kazakhstan or the drought in southern Africa (if this can be attributed to global warming). Environmental degradation in the economy is mirrored primarily through citizens' concerns about ecosystem damage, not through declines in productivity. Many of the ecological-economic papers in this book just may be misguided.

This book collects 13 papers presented at "Economics of the Environment," a conference organized by the Center for Economic Research at Tilburg University, the Netherlands, in September 1990. It contains theory papers (optimal control, input-output analysis), simulations, experiments, contingent valuation and benefit-cost analysis, and qualitative discussion pieces. The editors, to their credit, have done a good job organizing such diverse papers.

The section on "Environmental-Economic Modeling" contains papers on exhaustible resources, stock and flow pollutants, and population growth in the context of sustainability. Most notable is the paper by Henk Peer on sustainability, which has the grand title, "An Inquiry into the Nature and Causes of the Wealth of Planet Earth." This paper investigates sustainability using a neoclassical growth model and includes two elements that are important in analyzing sustainability, namely positive population growth and the use of finite, nonrenewable resources. Sustainability means "a constant savings/investment ratio, a constant average productivity of capital, and a constant stock of the exhaustible resource (measured in years)" (p. 66). The author concludes that under reasonable conditions there exists a sustainable steady state for the world economy. This encouraging scenario (per capita consumption rising at 2 percent per year) is undercut by a lack of model details or any mention of initial conditions.

The "Valuation of the Environment" section is even more wide-ranging, including an experimental analysis of learning about the value of a public good, a contingent valuation study of the transformation of peat bogs on Scotland to commercial forest, and a discussion of the political economy of environmental issues. This latter paper, "Ecological Perception and Distribution Conflicts," by Joan Martinez-Alier, is a criticism of modern economies' approaches to environmental problems. It finds fault with both neoclassical and ecological economics as economic paradigms. This chapter is a combination of poor or incorrect economic explanations and some genuinely good ideas, accompanied by some peculiar vocabulary like elucubrations, chrematistic, and narodnism.

The third section, "Environmental Policy," consists of three papers on the political economy of environmental policy instruments, legal aspects of marketable pollution permits, and the role of the firm in an "ecological economy." Marjan Peeters' chapter takes up legal issues pertaining to a tradeable-permits market that economists might otherwise overlook. For example, the "transfer of a pollution right will have as a consequence that the pollution will occur at another place or time than before" (p. 156), exposing private citizens who are near an industrial plant that purchases pollution rights to more pollution. Citizens' legal standing as "third persons," with certain rights pertaining to the pollutants they are exposed to, may depress the permit market if it results in few trades being allowed to take place.

The final section, "Economic Consequences of Environmental Policy," contains papers on carbon taxes in the United Kingdom, fertilizer use in the Netherlands, and chemical use in U.S. and EC agriculture. More focused than many others in the

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book, these papers show how specific environmental policies are modeled with enough information to understand the models. Economic ideas, however, take a backseat to the models' details. For example, Ingham and Ulph's paper makes clear how the effects of carbon taxes are modeled, but they fail to discuss effects on profits or gross domestic product.

Do Commodity Advertising and Promotion Pay?

Commodity Advertising and Promotion. *Edited By Henry W. Kinnucan, Stanley R. Thompson, and Hui-Shung Chang. Ames: Iowa State University Press, 1992, 409 pages, $44.95 (hardback).*

Reviewed by Gary W. Williams

Advertising to promote consumption of agricultural products and government support of these efforts have been around since the late 1800's. However, only in the past decade have agricultural economists begun to focus on the theory of commodity advertising and promotion and to measure the impacts in agricultural markets. Congress recently authorized mandatory producer assessments or "check-off" programs for milk (1983), beef, pork, and honey (1985), and soybeans (1990). The relatively huge sums of funds collected under these programs to support commodity promotion have spawned widespread debate regarding the effectiveness of such programs and the most efficient use of the funds collected.

Agricultural economists have responded to the need for information on the effects of commodity advertising, but in sources so diverse as to require extensive bibliographic searches. Fortunately, Kinnucan, Thompson, and Chang have pulled together 24 papers on agricultural commodity advertising and promotion research, originally presented at a 1989 conference sponsored by the Northeast Regional Committee on Commodity Promotion Programs (NEC-63).

Most papers in this volume focus on the response to advertising in various agricultural markets, including dairy, meat, potatoes, orange juice, wool, and fats and oils. The response measurement papers describe the theoretical basis of their work and the methodologies used in their analyses. Several other papers focus specifically on issues in theory and methodology.

The book includes six major topical sections. As is the case for most compilations of papers, however, the reasons for the particular organization of the papers are not clear. Consequently, the organization seems a bit arbitrary. The foreword by Olan Forker, Chairman of NEC-63, provides some background on the conference and its objectives but does little to help the reader understand how the book is organized, why the book is divided into those particular topical sections, and the importance of the contribution of each paper.

The first section ("Ongoing Empirical Research on Generic Advertising") offers seemingly "miscellaneous" papers presented at the NEC-63 conference. The papers range from newspaper advertising strategies for apples in North Carolina to the use of split-cable scanner data in commodity advertising research. Taken individually, the papers provide an interesting look at some innovative work on commodity promotion effects and the use of scanner data in advertising research.

"Incorporating Advertising into Demand Systems" benefits from Hayes's cogent summary and evaluation of five papers. The papers do little to determine whether advertising pays, but they offer excellent examples of incorporating advertising into demand systems and attempts to measure cross-commodity influences on advertising. Hayes contends that poor data preclude the measurement of commodity advertising effectiveness.

The third section, "Effectiveness of Brand versus Generic Advertising" examines the impacts of generic and branded advertising in the fresh/processed potato and orange juice markets. This section is instructive and insightful, but largely ignores the effectiveness of generic *versus* brand advertising, and, instead, analyzes the performance of generic *and* brand advertising.

"Attitudes in Advertising Research" first evaluates the potency of generic advertising in the pork industry using several analytical approaches, including a multistage model to consider how advertising shapes the attitudes of consumers of fresh pork and subsequent pork consumption. Also investigated is the relative importance of various attitudinal variables to the frequency and per capita use of milk and dairy products. The discussion paper at the end of this section does not address the other two papers but analyzes measur-

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ing commodity advertising effectiveness from the perspective of a commodity organization representative.

The fifth section looks at "Supply Response and Optimal Control Models of Advertising." The excellent study of the Australian wool promotion program uses household survey data to measure the payoff to wool promotion expenditures. However, the analysis is not done with an optimal control model, nor does the analytical model include a wool supply function. A study of beef promotion impacts on the livestock sector furnishes a rich inspection of the effectiveness of commodity advertising in an industry with a dynamic supply sector. Another study covers the optimal advertising expenditures for the New York State fluid milk promotion program, being an excellent primer on the use of optimal control models for commodity promotion analysis.

"Future Directions for Advertising Research" offers up well-considered suggestions in three areas: possible directions for future research, the information needs of producers and government agencies, and data requirements to support future research.

Should you add this book to your library? Yes, if you are involved in any aspect of commodity advertising and promotion research. Such a collection of papers on the current state of the art is simply not available elsewhere. The book gives researchers valuable insight on neglected problems from an agricultural industry perspective. Even nonresearchers associated with commodity promotion programs will profit from a better understanding of not only the commodity market effects of advertising but also the research methodologies used to measure those effects. The book also illustrates to policymakers and producers the tremendous data needs of researchers and the measurement limitations of current commodity advertising and promotion research methods.

The book contains: (1) Ongoing Empirical Research on Generic Advertising—"Newspaper Advertising of Apples in North Carolina: Characteristics and Comparisons across Cities and Time" by D. Ghura and R.A. Schrimper; "Assessing the Impact of Generic Advertising of Fluid Milk Products in Texas" by O. Capps, Jr., and D.S. Moen; "Impacts of Dairy Promotion from Consumer Demand to Farm Supply" by H.M. Kaiser, D.J. Liu, T.D. Mount, and O.D. Forker; "Evaluating Advertising Using Split-Cable Scanner Data: Some Methodological Issues" by H.H. Jensen and J.R. Schroeter; and "Discussion: Ongoing Empirical Research on Generic Advertising" by J.R. Blaylock; (2) Incorporating Advertising in Demand Systems—"Theoretial Overview of Demand Systems Incorporating Advertising Effects" by M.G. Brown and J. Lee; "Measuring the Effects of Advertising on Demand Elasticities Using Time Series/Cross-Sectional Data" by H. Chang and R. Green; "A Preliminary Look at Advertising Beef, Pork, Chicken, Turkeys, Eggs, Milk, Butter, Cheese, and Margarine in Canada" by E.W. Goddard and B. Cozzarin; "A Rotterdam Model Incorporating Advertising Effects: The Case of Canadian Fats and Oils" by T.L. Cox; "Performance of the AIDS Model for Advertising Evaluation: Results based on Canadian Data" by H. Chang and H.W. Kinnucan; "Discussion: Incorporating Advertising into Demand Systems" by D. Hayes; (3) Effectiveness of Brand versus Generic Advertising—"Advertising of Fresh and Processed Potato Products" by E. Jones and Y. Choi; "Commodity versus Brand Advertising: A Case Study of the Florida Orange Juice Industry" by J. Lee and M.G. Brown; "Discussion: Generic and Brand Advertising" by R.W. Ward; (4) Attitudes in Advertising Research—"Evaluating the Effectiveness of Generic Pork Advertising: The First Fifteen Months" by S. Hoover, M. Hayenga, and S.R. Johnson; "Health Concerns and Changing Consumer Attitudes toward Characteristics of Dairy Products: A Selected Analysis of the Attitude, Usage, and Trends Survey Data (AUTS), 1976-1988" by C.S. Thraen and D.E. Hahn; and "Discussion: Communicating Economic Research" by B.D. Pfouts; (5) Supply Response and Optimal Control Models of Advertising—"Measuring Wool Promotion Response with Household Survey Data" by J. Dewbre and S. Beare; "Impacts of Promotion on the Livestock Sector: Simulations of Supply Response and Effects on Producer Returns" by H.H. Jensen, S.R. Johnson, K. Skold, and E. Grundmeier; "An Economic Analysis of the New York State Generic Fluid Milk Advertising Program Using an Optimal Control Model" by D.J. Liu, J.M. Conrad, and O.D. Forker; and "Discussion: Supply Response and Optimal Control Models of Advertising" by B.L. Dixon; and (6) Future Directions for Advertising Research—"Government Policy and Program Information Needs" by C.R. Brader, K.M. Kesecker, and H.S. Ricker; "Generic Advertising: A Commodity Perspective" by A. MacDonald and P. Gould; and "Future Directions for Advertising Research" by S.R. Johnson.

New World Trading Order Undercut by Regional Accords and Ecoprotectionism

The Political Economy of Agricultural Trade and Policy: Toward a New Order for Europe and North America. *Edited by Hans J. Michelmann, Jack C. Stabler, and Gary G. Storey. Boulder, CO: Westview Press, 1990, 242 pages, $28.50.*

Reviewed by Mark V. Simone

The Uruguay Round of the General Agreement on Tariffs and Trade (GATT) negotiations have shown that the inextricable link between economics and politics can be a considerable obstacle for agricultural trade reform. *The Political Economy of Agricultural Trade and Policy: Toward a New Order for Europe and North America* is an outgrowth of a conference held in Saskatoon, Saskatchewan, in March 1990 that addressed the ramifications of trade reform.

This collection of papers is accessible and readable. Readers with a cursory understanding of farm policies in Europe and North American will readily understand the authors' presentations. However, analysts of agricultural policy for the Uruguay Round will probably already know much of what is presented here.

The first section of the book covers the development of European Community (EC), Canadian, and the U.S. agricultural policies. Each chapter concludes with the motivation for reform (mainly budgetary) of agricultural policies in light of the Uruguay Round. The chapters ease the reader into the often complex agricultural policy milieu of developed countries.

Tracy's chapter provides a good overview of the EC's evolution and the need for Common Agricultural Policy (CAP) reform without dwelling on complicated CAP aspects such as monetary compensatory amounts and green rates. Tracy notes that the CAP "was not created in a vacuum but was an amalgam of existing national measures." He illustrates this point through examples of the struggle among the six founding members of the EC in forming the CAP.

Skogstad's chapter summarizes the agricultural policy process in Canada revealing the differing policy orientations of the various commodity sectors, from the supply-managed dairy and poultry sectors to the market-oriented hog and cattle industry. The obvious tensions in policy formation within Canada explain the evolution of Canada's current GATT position away from the United States. A discussion of the ramifications of Quebec's threatened secession over the failure of proposed constitutional reforms would have been insightful. Because Quebec has a significant portion of the dairy sector, with a strong political base, some changes in Federal policy orientation could be anticipated with Quebec's secession.

Rausser's chapter on the United States is the most ambitious and rigorous of the three. It utilizes his concept of predatory (PEST's) and productive (PERT's) agricultural policies, presenting several examples of both types in U.S. agriculture. U.S. agricultural polices, Rausser contends, are neither formed solely by the U.S. Government seeking welfare corrections of market failure nor by powerful, rent-seeking interest groups. Rather, policies result from tradeoffs between public and private interests.

The book's second section deals with the structural change of agriculture in the EC, Canada, and the United States; the growing pressures for reform of their agricultural policies; and the impact of GATT on this reform. The chapters complement each other well. Brinkman's chapter on structural changes is straightforward, containing tables ample with farm indicators in the EC, Canada, and the United States. The plethora of data shows that farming is on a much smaller scale in the EC relative to Canada and the United States. EC farmers are more dependent on agriculture for a livelihood than are Canadian and U.S. farmers, whose off-farm income continues to grow in importance.

Veeman and Veeman utilize the "tried and true" producer and consumer subsidy equivalents to depict increasing Federal support for agriculture during the 1980's and the budgetary exposure that prompted policy reform. They argue that the trends presented in Brinkman's chapter (increasing farm sizes, declining farm numbers, greater off-farm income) will continue and result in a movement toward market-oriented policies, accompanied by decoupled support to farmers truly in need. Such policies would be in contrast to current U.S. programs for grains and cotton, where the largest farms often accrue most of the benefits.

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Josling chronicles the Uruguay Round for agriculture from its start in September 1986 up to the comprehensive final proposals in the fall of 1989. Josling portrays the Organization for Economic Cooperation and Development's publication of producer subsidy equivalents as a turning point in trade negotiations since "details of national policies were openly discussed for the first time in a quantitative framework." Not all agricultural economists will want to relive this period, but the chapter provides a detailed reference. The book's publication preceded the Round's current impasse over agriculture, but Josling prophetically admits that sweeping change in agricultural policies under the GATT "flies against all experience of recent history and ignores political realities."

The final section utilizes the topical phrase "new world order" to discuss possible change in agricultural policies. Runge portends the growing importance of nontariff barriers (NTB's) to trade in future trade negotiations, especially in the areas of health, safety, and the environment. He characterizes these NTB's as "ecoprotectionism." While I do feel that the Uruguay Round conclusion will ultimately be more modest than what Runge asserts, I have no qualms about his ecoprotectionism claim, particularly after the flap concerning the banning of U.S. beef and pork from the EC for health reasons and the continuing controversy over the growth hormone, bovine somatotropin (BSt), in several countries.

Fulton and Storey address the possibility of a new world order for agricultural policy by looking at the evolution of agricultural policy from 1800 to the present in the United States, France, Germany, and Great Britain. Their approach is useful since it ties several important world events to policy changes, which often were a reaction to occurrences such as the Irish Potato Famine and Great Depression. In terms of the U.S. and EC wheat markets, the authors argue that a move to free trade would benefit the United States and reduce the EC agricultural budget but be politically untenable to the EC. As an alternative, they suggest production controls in both regions, which would be less damaging to EC producers than would free trade. However, the collapse of various International Wheat Agreements during the 20th century makes me skeptical about market sharing for agricultural trade.

Since the publication of this book occurred before the December 1990 collapse of the GATT negotiations, several authors' optimism for a significant agreement on agriculture may have been premature. The conclusion of negotiations for a North American Free Trade Agreement (NAFTA) and the EC's 1992 economic integration program have possibly tarnished multilateral trading structures in favor of regional trading arrangements. However, politics and economics are often at loggerheads in these trade discussions. I would enjoy reading another compendium focusing on regional trade by these same authors.

The book features: **The Political Economy of Agriculture**—"The Political Economy of Agriculture in the European Community" by Michael Tracy; "The Political Economy of Agriculture in Canada" by Grace Skogstad; "The Political Economy of Agriculture in the United States" by Gordon C. Rausser. **The International Agricultural and Trading Environment**—"Structural Change in Canadian, United States, and European Agriculture" by George L. Brinkman; "The Crisis in European and North American Agriculture" by Michele M. Veeman and Terrence S. Veeman; "The GATT: Its Historical Role and Importance to Agricultural Policy and Trade" by Tim Josling. **Prospects for a New World Agricultural Order**—"Prospects for the Uruguay Round in Agriculture" by C. Ford Runge; "A New World Agricultural Order?" by Murray Fulton and Gary G. Storey. **Conclusion**—"Concluding Remarks" by Hans J. Michelmann and Jack C. Stabler.

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